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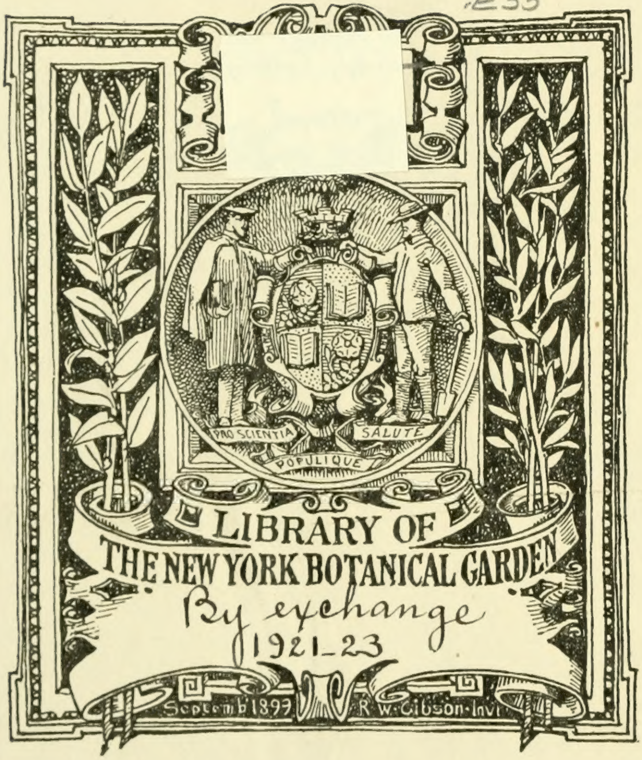
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BOTANICAL SERIES

Volume XI

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AGRICULTURAL RESEARCH INSTITUTE, PUSA

PRINTED AND PUBLISHED FOR
THE IMPERIAL DEPARTMENT OF AGRICULTURE IN INDIA

BY
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W. THACKER & CO., 2, CREED LANE, LONDON

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September 1920. Botanical Series Vol XI, No 1.

Memoirs of the Department of Agriculture in India

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BY
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Imperial Economic Botanist
AND
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SOME ASPECTS OF THE INDIGO INDUSTRY IN BIHAR.

PART I.

THE WILT DISEASE OF INDIGO IN BIHAR.

BY

ALBERT HOWARD, C.I.E., M.A.,
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[Received for publication on 23rd November, 1919.]

When the Indigo Research Station at Sirsiah was closed on March 31st, 1913, investigations on the agricultural and botanical aspects of this industry were transferred to the Botanical Section of the Agricultural Research Institute at Pusa. About this time, the cultivation of Java indigo in Bihar had reached its lowest point, having fallen from 70,000 to about 15,000 *bighas* between 1910 and 1914, largely on account of the wilt disease and the difficulty of obtaining seed. These and other aspects of the industry have been under investigation during the last six years. An account of the earlier results appeared in Bulletins 51, 54 and 67 of the Agricultural Research Institute, Pusa. The present paper deals with the causes of indigo wilt and with its prevention.

Java indigo (*Indigofera arrecta* Hochst.) is a perennial tropical crop which was first introduced into Bihar from Java in 1898. The climate of Bihar is tropical, as far as temperature is concerned, from March to November, but December, January, and February are too cold for the growth of this crop. When first introduced, Java indigo did exceedingly well, yielding heavy crops of leaf, rich in *indican*, as well as abundant seed. After some years, however, the plant began to show increasing signs of want of vigour and finally began to die of wilt during the second half of the rainy season. At the same time, the yield of seed diminished. The degeneration was progressive and by 1913, when we took up this investigation, many planters had already abandoned the cultivation while others had considerably restricted the area under this species.

Wilt usually makes its appearance after the first cut during July and August, the severity of the attack depending on the season. Affected plants stand out clearly from normally grown individuals and are easily recognized in the field. At first, there is a slowing down of growth while the foliage alters in appearance, the leaves become folded longitudinally and assume a yellowish-green, slaty colour. Leaf-fall is then rapid until only a tuft of stunted foliage is left at the tips of the branches. Afterwards, the plants die off in stages, the process taking place slowly, a branch at a time.

A good deal of attention has been devoted by previous investigators to the cause of indigo wilt. Neither insects, fungi nor bacteria have been shown to be responsible for the trouble. Our investigations indicate that wilt results from the destruction of the fine roots and nodules under circumstances when regeneration is difficult or impossible. In the following pages, the evidence is recorded on which this conclusion is based. Before dealing with the actual observations and experiments, a brief reference to the chief factors underlying the cultivation of Java indigo in Bihar is necessary to bring out the significance of much of the following.

I. THE FACTORS.

Soil. The soil of the Bihar indigo districts is a silt (often containing large quantities of finely divided calcium carbonate) belonging to the older alluvium of the Gangetic plain. Its main characteristics, from the point of view of the indigo plant, are its depth, the uniformity of its fine particles, its water holding capacity during the hot months of April, May, and June, the comparative nearness to the surface of the sub-soil water and the low content of oxygen in the deeper layers, as shown by the analyses of well-waters. The sub-soils often show rust coloured markings associated with green and blue tints which, according to Hilgard,[1] indicate a lack of aeration in consequence of imperfect drainage. The indigo soils easily run together on the surface after moderate rain forming a well-defined crust, known to the cultivator as the *papri*. After long continued heavy rain, this crust may become several inches thick, the porosity of which is not recovered until the land dries and is cultivated. An excessive rainfall besides producing these impermeable crusts, also leads to the waterlogging of the pore spaces of the upper soil (probably due to deflocculation of the clay particles) for comparatively long periods.[2]

Rainfall. The average annual rainfall is in the neighbourhood of 50 inches, most of which falls during the period May to September (Table 1).

[1] Hilgard, "Soils," 1906, p. 45.

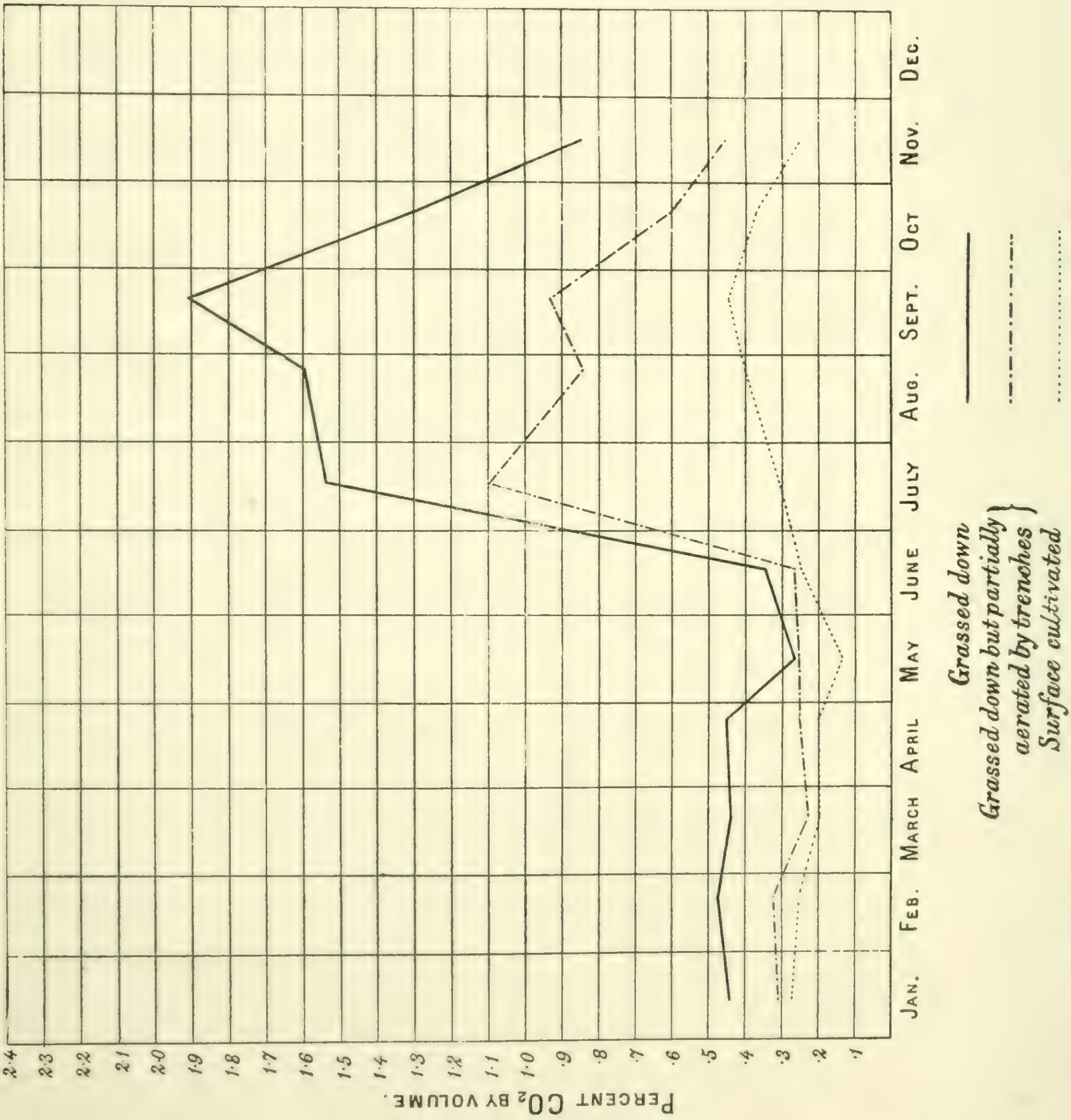
[2] *Agr. Jour. of India,* Special Indian Science Congress Number, 1919, p. 381.

TABLE I.

Rainfall at Pusa during the years 1906–1919.

Month	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	Average
January	..	0·00	0·47	0·11	0·01	0·27	0·13	0·00	0·00	0·13	0·00	0·13	0·00	1·29	0·18
February ..	2·29	1·22	2·27	0·00	0·02	0·00	0·11	1·44	0·97	1·73	0·44	0·75	0·00	0·02	0·80
March	0·21	1·77	0·10	0·23	0·07	0·57	0·80	0·43	0·11	1·31	0·00	0·32	0·09	0·02	0·43
April	0·00	0·89	0·00	3·47	0·14	0·44	1·18	0·01	1·94	0·26	0·31	0·00	0·69	1·36	0·76
May	1·93	0·33	0·92	1·34	0·41	0·33	3·14	7·00	1·86	1·99	0·37	3·48	3·69	0·68	1·96
June	5·48	6·88	1·48	28·96	7·46	11·79	4·61	17·71	4·21	5·07	9·67	7·96	11·50	2·21	8·93
July	11·99	7·68	7·24	10·08	9·34	9·21	14·48	10·22	10·19	16·25	10·62	12·51	11·64	14·78	11·16
August	24·81	6·14	3·85	24·11	6·88	17·98	9·63	18·57	28·83	21·97	15·85	5·35	26·68	5·54	15·44
September	3·06	14·80	4·97	4·51	3·70	8·09	3·33	8·17	6·13	4·67	13·90	10·77	6·43	5·11	6·97
October	0·57	0·00	0·58	2·90	4·16	3·13	0·16	1·07	0·09	0·93	4·95	1·88	0·00	1·89	1·59
November	0·00	0·00	0·00	0·00	0·14	0·71	4·03	0·00	0·00	0·56	0·00	0·00	0·00	..	0·39
December	0·00	0·00	0·04	0·12	0·00	0·00	0·00	1·13	0·03	0·02	0·00	0·01	0·00	..	0·10
TOTAL	50·34	39·71	21·92	75·83	32·33	52·52	41·60	65·75	54·36	54·89	56·11	43·16	60·72	32·90	48·71

PLATE I.



CARBON DIOXIDE IN THE SOIL ATMOSPHERE AT PUSA.

July and August are the wettest months. From November to April very little rain is received. The humidity is generally high and is lowest in March and April when it falls to about 60.

Temperature. There is a well-marked cold season, December to February, when the minimum temperature remains in the neighbourhood of 50°F. In the hot weather months, March, April and May, the dry west winds are important agents in improving the aeration of the soil. The monsoon period June to September is hot and damp. After the middle of October, the temperature gradually falls till cold weather conditions set in at the end of November.

Soil aeration. Periodical determinations of the amount of carbon dioxide in the soil atmosphere have been carried out in the Botanical area at Pusa by Mr. Jatindra Nath Mukherjee under the direction of Dr. Harrison, Imperial Agricultural Chemist, on cultivated and grass land for a period of eleven months. The results are given in Table II and in Plate I. A note by Mr. Mukherjee on the methods adopted is appended to this paper.

TABLE II.

Percentage of CO_2 in the soil gas from three different plots in the Botanical Area, Pusa, in 1919.

Date and month when the soil gas was aspirated and analysed	Plot No. 1 Grassed down	Plot No. 2 Grassed down but partially aerated by trenches	Plot No. 3 Surface cultivated	Rainfall in inches since 1st January, 1919
13th, 14th and 17th January	0·444	0·312	0·269	*Nil.*
20th and 21st February ..	0·472	0·320	0·253	1·30″
21st and 22nd March ..	0·427	0·223	0·197	1·33″
23rd and 24th April ..	0·454	0·262	0·203	2·69″
16th and 17th May ..	0·271	0·257	0·133	3·26″
17th and 18th June ..	0·341	0·274	0·249	4·53″
17th and 18th July ..	1·540	1·090	0·304	14·61″
25th and 26th August ..	1·590	0·836	0·401	23·29″
19th and 20th September ..	1·908	0·931	0·450	30·67″
21st and 22nd October ..	1·297	0·602	0·365	32·90″
14th and 15th November ..	0·853	0·456	0·261	32·90″

These figures and the curves (Plate I), give a general idea of the soil atmosphere as regards ventilation in a year exceedingly favourable to the indigo crop. Aeration is at its best during the period of the west winds—March to May. After the monsoon has set in, the proportion of carbon dioxide rises and remains at a fairly high level till October when it rapidly falls.[1] Of perhaps greater significance in this respect are the movements of the ground water. In the indigo areas of Bihar, the flow of the rivers is often checked during the monsoon by the rise of the level of the Ganges. As a result, the rivers overflow and the lowlying areas go under water. The rise in the level of the rivers is followed by a rise in the water-level of the wells. These movements of the river level and of the general ground water are illustrated in the curves opposite (Plate II) which represent the state of affairs of the river at Pusa and of one of the wells (about a quarter of a mile distant from the river bank) for the years, 1910, 1912, 1913 and 1914. This upward movement of the ground water, which must push in front of it the soil air from the deeper layers, occurs at a period when the general drainage of the country is checked and when the permeability of the surface soil is poor due to consolidation by heavy rain. We should expect, therefore, that the aeration of the soil will be at its lowest point during the second half of the rainy season.

Briefly stated these are the conditions under which a tropical leguminous plant has to grow in Bihar. The range is wide. The crop is sown at the end of the rains in late September or early October, when the surface soil is sufficiently warm and moist for rapid germination. By the beginning of the cold weather in December, the plant is three or four inches high. Growth then ceases till March. After the rains set in towards the end of May or early in June, growth is exceedingly rapid and the first cut is taken at the end of June or early in July. The stumps shoot again and the second crop is harvested in late July or early August, followed, in good years, either by a final cut in September or by a crop of seed during the cold weather. After this, the stumps are dug out and the land is prepared for other crops. The original practice in Bihar was to raise the seed after at least two crops of leaf and at a period in the life-history of the plant when its vigour was at its lowest point.

II. The Cause of Wilt.

The earlier results relating to the cause of wilt of Java indigo were published in 1916, in *Pusa Bulletin* 67. Since that time, the subject has been investigated afresh but in much greater detail with the consequence that our former conclusions have been confirmed in all respects. Briefly stated, we have found that when the roots and nodules of an indigo plant have suffered extensive damage, wilt invariably results from any cause which interferes with

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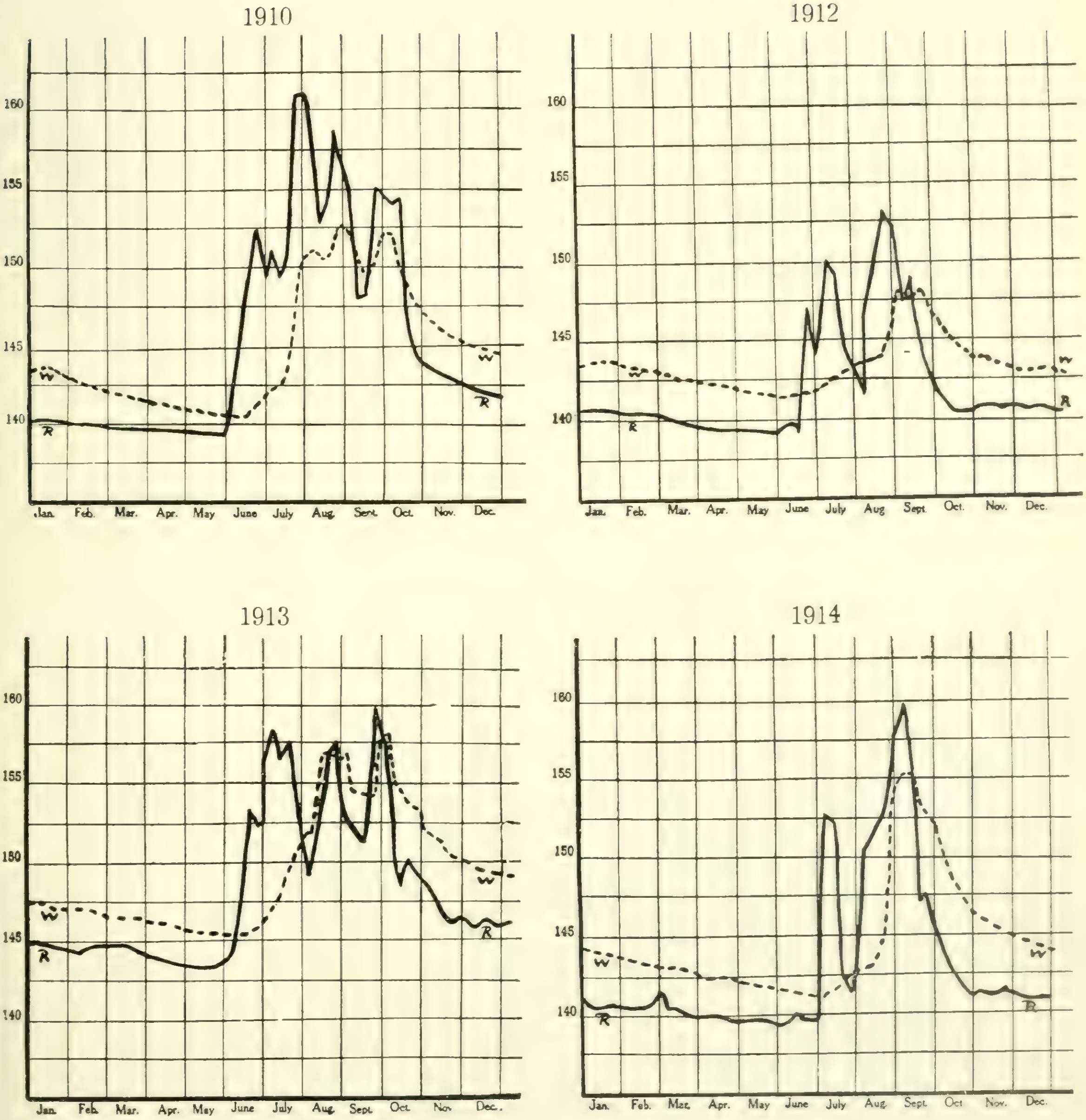
[1] It is possible that other deleterious substances beside carbon dioxide are produced in Bihar subsoils during the rainy season. The subject needs further investigation.

PLATE II.



CHANGES IN THE RIVER AND WELL LEVELS AT PUSA.
The well levels shown by dotted lines. The observations are expressed in feet above mean sea level.

normal root regeneration. Several factors have been discovered which prevent the repair of the root system. In indigo cultivation, the chief source of damage to the active roots and nodules arises from the complete cutting back of the plant.[1] This results in the destruction of practically all the fine roots and nodules and root regeneration is necessary before new growth can take place. If the absorbing root system is destroyed when the soil aeration is poor, when the amount of reserve material in the tap root is insufficient for new roots to be formed, or when the soil temperature is too low for growth, root regeneration becomes exceedingly difficult and wilt follows. Thus although the cause of wilt is the same in all cases, the agents which produce it may be different. In considering the incidence of wilt in Bihar, it is necessary, therefore, to understand fully in every case the factors which are concerned in root regeneration. If this is done, all the known cases of wilt fall together and are capable of a simple explanation.

As the nodules and active root system appeared to be of particular importance in this question, a great deal of attention has been paid thereto. The condition of the roots and nodules, however, cannot be determined with precision by observation of the above ground portion of the crop. It was necessary to find some easy method of rapidly exposing without damage the complete root system including the finer branches and the nodules. This was accomplished by the use of an ordinary knapsack sprayer. The results obtained by following the root development throughout the year have proved of the very greatest value in the elucidation of this interesting problem.

Root development in Java indigo.

The development of the root system of the ordinary indigo crop, sown in late September or early October, has been examined for several seasons by means of periodical root washings. At first, the tap root extends rapidly in length and by the beginning of the cold weather practically no large laterals are developed. The root system at this stage consists of a long tap root with comparatively fine laterals and a certain amount of nodular development. During the cold weather, the extent of the active absorbing system is small and little or no growth of roots takes place. With the renewal of activity at the beginning of the hot weather in March, new absorbing roots are copiously developed and the laterals increase in thickness. Nodular development begins in April, but does not become intense till the soil is cooled and moistened by the early monsoon rains in May when the numbers formed are very large. As would be expected, these bodies are much more abundant in the first four inches of soil than in the deeper layers. No further changes occur till the first cut is taken. Cutting back is followed by the destruction of practically all the fine roots and of most of the nodules. Before new growth can take place, root regeneration is necessary. The extent and speed of this regeneration is found to depend on the aeration of the soil. If the rainfall is low and if the levels of the rivers and wells do not rise to any great extent, as in 1919, the fine roots and nodules are rapidly renewed. Thus in the case of the root systems of three plants exposed on June 14th, 1919, 194 nodules were found on the upper laterals. These were removed and the soil quickly replaced. A month later, the roots of these plants were again exposed and numerous new fine roots and no less than 942 fresh nodules were found. The reaction of the roots to alterations in the soil atmosphere during the rains is very striking. After the middle of July and at the beginning of September of the present year, 1919, when heavy rains, combined with the rise of the ground water, adversely affected the aeration of the soil, an immediate root response to the changed soil conditions took place. The fine roots in the deeper layers of soil were quickly killed, new roots were only formed near the surface of the ground while the finer branches of the upper laterals were found to exhibit marked aerotropism and to bend upwards towards the air. This continued on both occasions till a break in the rains and a fall of the ground water restored soil aeration when normal root development again ensued. During the late rains, the formation of fine roots and nodules is almost always restricted to the upper four inches of soil. At this time, the lower regions of the tap-root and the lower laterals are practically devoid of nodules and small roots and the current of crude sap is maintained entirely by the fine roots near the surface of the ground. This is effective while monsoon conditions prevail but when the rains cease and the upper layers of the soil dry, the plants either become wilted or else shed their leaves and pass into a resting condition during the cold weather.[1] Root and shoot growth are resumed when the soil temperature rises in March.

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[1] A large number of root washings have been made, at all stages of growth, after indigo plants have been cut back to varying extents. Complete cutting back always kills the fine roots and most of the nodules. Heavy pruning results in extensive root and nodular destruction but not to the same extent as when the plants are completely cut back.

In the case of Java indigo sown for seed in August, the feature of the root system is the development of abundant nodules on the upper roots during late September and October. These, however, become absorbed during

---

[1] Mulching the soil to prevent the loss of moisture acts as a preventative of wilt during October, November and December.

November and December after flowering sets in. During the cold weather, the roots of seed plants show few active rootlets and extensive regeneration does not take place till the temperature of the soil rises in March.

In both the ordinary and the seed crop, therefore, the features of the root system may be summed up as follows :—

(1) The periods of intense nodular development are at the break of and during the early rains and, in the case of the seed crop, in September and October.

(2) Temperature, soil aeration and moisture are the chief factors in the formation of absorbing roots and nodules.

(3) Although the nodules and fine roots are easily destroyed, the main tap-root and the larger laterals possess remarkable vitality and are capable of remaining dormant in the soil without damage from December to March, after which they often produce a new set of absorbing roots and nodules.

Observations and experiments on the cause of wilt.

The evidence on which we have based our conclusions as to the cause of wilt has been obtained by several methods. The root systems of numerous healthy and wilted plants have been compared in detail, the occurrence of wilt in Bihar has been studied under various conditions extending over many years, actual cases of wilt have been produced artificially in no less than five different ways while many examples of recovery have been closely examined. The conclusions arrived at, as a result of these experiments and observations, have been confirmed by a study of the behaviour of other crops during the rains at Pusa and also by the growth of indigo, on soils differing widely as regards aeration, in other parts of India.

The root systems of wilted and healthy plants. The roots of a very large number of wilted plants have been exposed by the spraying machine and compared with those of healthy plants. The results have always been the same. Where the wilted condition is well marked, healthy nodules are never found while the number of active roots is exceedingly small. Dead and discoloured fine roots and nodules are, however, abundant. In the case of the roots of healthy plants examined at the same time for comparison, there have always been abundant fine roots and root nodules in an actively growing condition. Indigo wilt is, therefore, associated with the recent destruction of the absorbing root system.

In the rains, wilt occurs on deep-rooting types to a much greater extent than on those with a shallow root system. Java indigo, as grown in Bihar, is an exceedingly mixed crop and consists of a large number of types which, however, fall into two main classes as regards branching and root development :—

(1) Bushy types which branch to very varying degrees from the base, the branches coming off nearly at right angles to the main axis. There is a general correspondence between the method of branching of the stem and of the root. The root system is the mirror image of the shoot. In those bush types which branch at right angles to the axis, the lateral roots are also given off at right angles to the main tap-root.

(2) Tall vertical types whose branches arise at an acute angle from the stem. In the vertical types, the lateral roots arise at an angle very similar to that in the case of the branches.

These general differences are shown in Figs. 1 and 2 and in Plate III. Running through both these classes of branching are great divergencies in the time of flowering and in the rate of growth. Some are early, others are exceedingly late. Some grow slowly, others much more rapidly. All grades of intermediates naturally occur. Five main types of root-development have up to the present been found :—

(*a*) Early bush types in which nearly all the laterals arise at right angles and are concentrated near the surface. Our selected indigo, known as Type 15, belongs to this group. The root system is shown in Fig. 1.

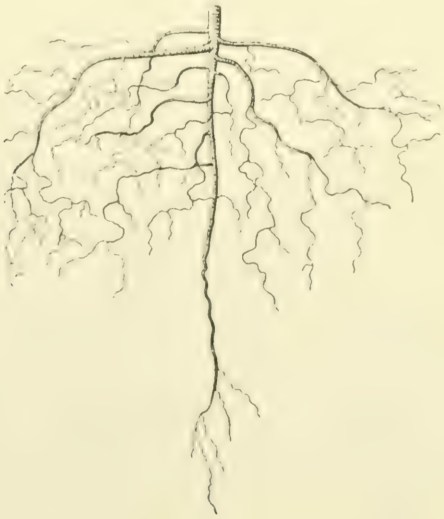
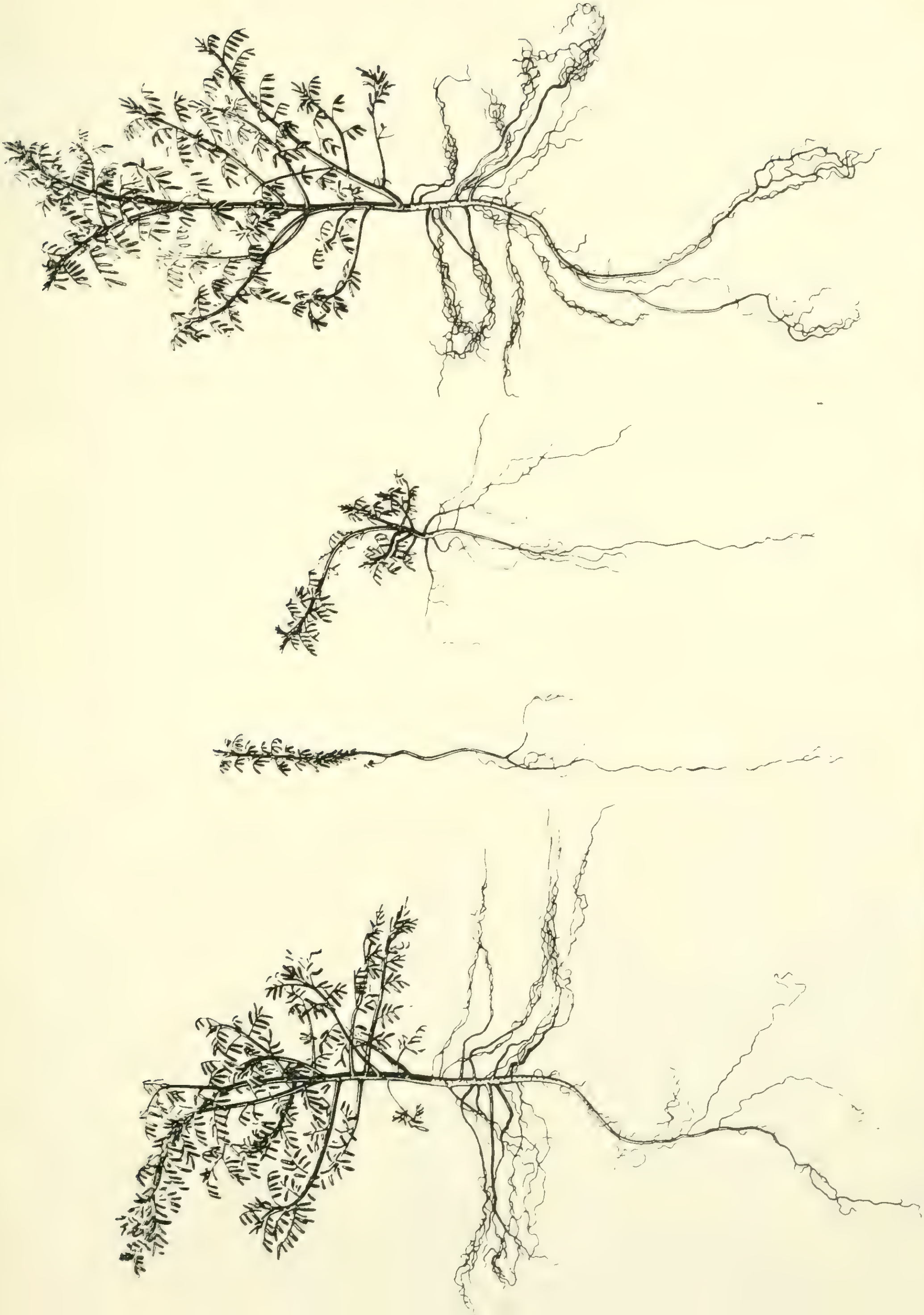


Fig. 1. The root-range of an early bush type of Java indigo.



THE ROOT-RANGE IN EARLY-FLOWERING TYPES OF JAVA INDIGO.

(*b*) Early types with a vertical habit in which nearly all the laterals are concentrated near the surface but all point downwards. The selection known as Type 11, the roots of which are shown in Fig. 2, belongs to this type.

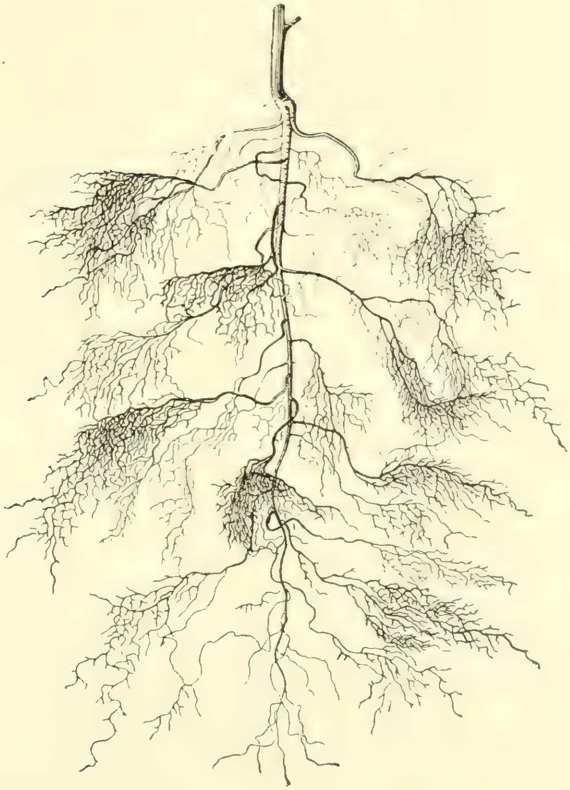


Fig. 2. The root-range of a plant of Java indigo of vertical habit.

(*c*) Late bushy forms in which there is a development of lateral roots from the surface to a great distance down the main root.

(*d*) Late types of vertical habit with lateral roots pointing downwards arising at regular intervals down the long main root.

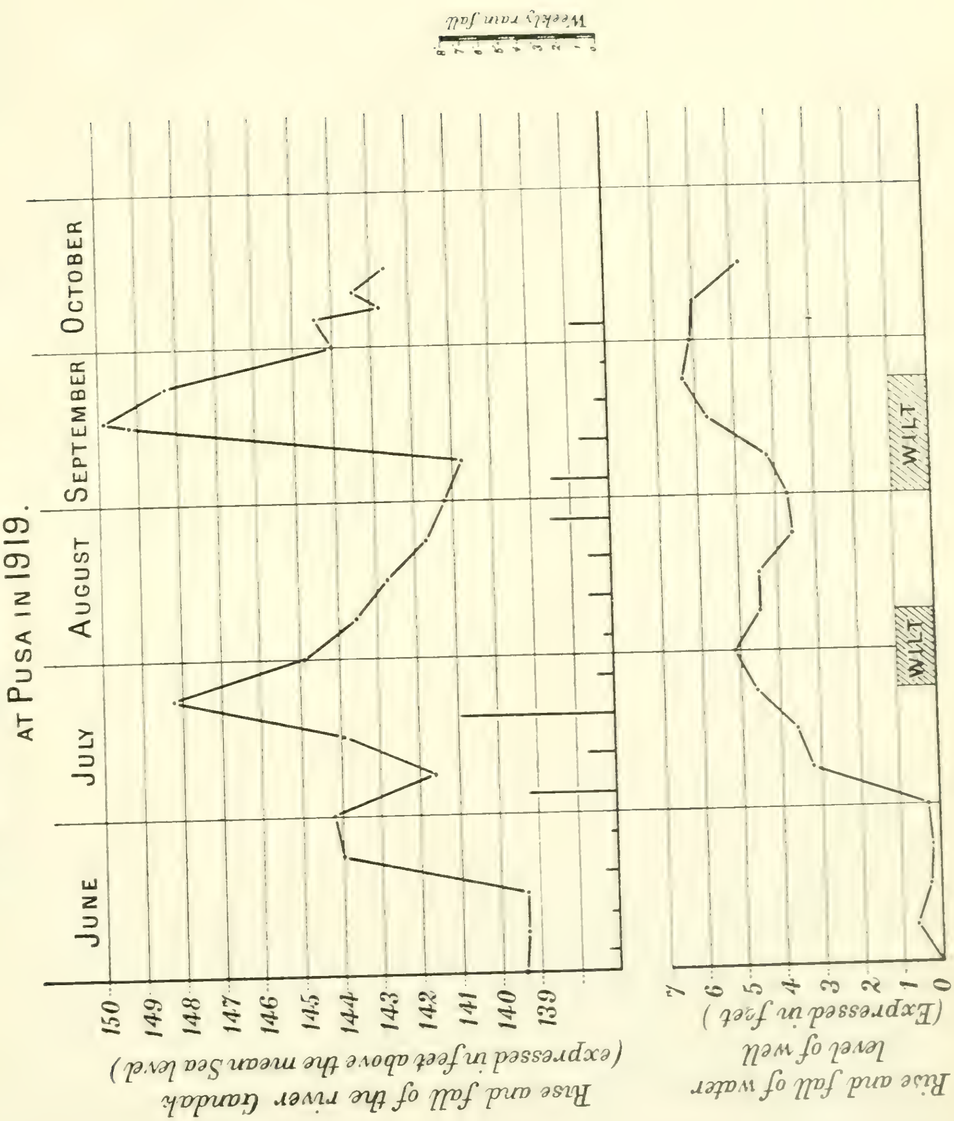
(*e*) Types with hardly any side branches but a deep tap-root. These types scarcely branch at all either above or below ground.

It will be obvious that if poor soil aeration is a factor of importance in the production of wilt, the types which will be affected most are deep-rooting types like (*b*), (*c*), (*d*) and (*e*) while (*a*) will be least affected. In 1917, a comparison was made between the growth and wilt resistance of Type 11, an early type with a vertical habit whose laterals point downwards (Fig. 2) and Type 15, an early bush type with laterals near the surface (Fig. 1). The former proved to be much more wilt liable than the latter. In 1918, this point received further confirmation. It was found that after the first cut, all the plants which did not shoot and which were attacked by wilt could not be uprooted by hand as the laterals ran deep into the soil. On the other hand, the plants which formed healthy new growth could be pulled up with comparative ease as the laterals were much nearer the surface. In 1919, every case of wilt examined in detail during the monsoon was found to be associated with deep-rooting while the healthy plants examined for comparison were all found to be surface-rooted.

The occurrence of wilt under monsoon conditions. The amount of wilt during the rainy season and the general vigour of the indigo crop under estate conditions, have been found to depend on two factors—the rainfall and the rise of the ground water. If the rainfall is heavy, particularly during July and August, and if the ground water rises rapidly and remains at a high level during this period, the second crop is a failure and wilt is widespread. Although unfavourable years are common, they are not universal. In 1919, the monsoon rainfall was about 12 inches below the average, there were no floods and the rise of the ground water was not considerable. The details relating to the rainfall and to the movements of the river and well levels at Pusa, in 1919, are given in Plate IV. Wilt was negligible and only made its appearance on two occasions—between July 23rd and August 7th—and again during the first three weeks of September. Both these attacks were associated with an increased rainfall and a rise in the well levels. They were, however, not severe and had little influence on the yield. Three good cuts of indigo were obtained at Pusa and for many years the indigo crop has never been so healthy after the rains.

Although wilt is often universal during the late rains, it is not uncommon in Bihar to find young self-sown indigo plants in September and October, growing vigorously in fields practically destroyed by disease. In 1912, at Pusa, this occurred on the large scale in a wilted field in which the blank spaces in the lines had been filled by resowing during the first week in August. The late sown plants without exception were not affected by wilt but grew well and gave heavy crops of well-ripened seed. Here, healthy and wilted

RISE AND FALL OF THE RIVER AND WELL LEVELS AT PUSA IN 1919.



plants grew next to next with interlocking root systems and in no single instance did wilt spread to the late sown plants. Since 1912, many similar examples have been noted which prove conclusively that wilt is neither a disease in the ordinary sense, nor is it caused by any deficiency in the soil solution.

Not only may wilted and healthy plants exist side by side, but it is easy to produce a wilted branch as well as vigorous growth on the same plant at the same time. This phenomenon occurs if a branch is left at the first cut in June to maintain the transpiration current. The result of this is that the damage to the fine roots and nodules (as shown by root washings) is less than if the plant is completely cut back while the new shoots are formed much more quickly. It often happens in such cases that after the new growth is well established near the ground, the old branch left begins to show signs of wilt which, however, does not spread to the new shoots. This is probably due to the utilization of the crude sap by the new growth near the ground level and the consequent slow starvation of the upper branch.

Both during the early and the late rains, deep cultivation has the effect of producing wilt. Two well-marked cases of this have occurred at Pusa recently. In 1918, Java indigo, sown in double lines to admit of interculture during the monsoon, steadily lost in vigour compared with the broadcast crop side by side and also developed more wilt. In the present season, 1919, the experiment was repeated with four types of indigo and on different classes of land. In most cases, the indigo grown in double lines with interculture yielded less green plant and also developed more wilt than the neighbouring broadcast plots. The effect of the cultivation was found to destroy the lateral roots near the surface and to stimulate root formation in the deeper soil layers. The lower roots were destroyed by poor soil aeration and the plants therefore developed wilt.

Wilt is easily produced after the rains during October and November by the cultivation of old indigo which has hitherto managed to survive at this period, the only active roots are close to the surface and the indigo plants are dependent on these. Cultivation or the natural drying of the surface soil destroys the surface roots and wilt occurs. It can be prevented by mulching such plants with straw or dried grass after the sowing rains in October. The mulch preserves the moisture and so assists the surface roots to maintain the indigo till growth ceases during the cold whether.

In 1919, a comparison was made between mulched and non-mulched plants. The former held their leaves and resisted wilt while the latter were affected by the trouble.

The artificial production of wilt. Wilt can be artificially produced in the following ways :—

(*a*) By mutilation of the root system.

(*b*) By cutting back young rapidly growing August sown plants in October, when the reserve materials in the tap-root are insufficient for root regeneration.

(*c*) By October and November cultivation of old indigo dependent for its crude sap on superficial roots.

(*d*) By complete cutting back in the cold weather, when the root regeneration of surface-rooted types is difficult on account of the low soil temperature.

(*e*) By waterlogging slowly from below during the rains by closing the drainage openings of lysimeters.

Undoubted wilt has been produced by root mutilation in two cases. The first occurred in a plant which was pruned on June 21st, 1919. The roots were exposed on July 15th, and found healthy in all respects. Before replacing the soil, the tap-root was severed at a depth of one foot below the surface and most of the fine roots were destroyed. Wilt developed. The second example occurred in the case of a plant which was pruned on June 21st, 1919. The roots were exposed on August 5th and were found to be normal. Before replacing the soil, all the fine roots and nodules on the laterals were removed to a depth of one foot but the tap-root was left intact. Wilt rapidly developed and when the root system was again exposed on August 29th, very few active roots were found.

The complete cutting back, about mid October, of young actively growing August sown indigo is certain to result in numerous cases of wilt. In 1914, three plots of August sown indigo, each a quarter of an acre in area, were cut back about the middle of October. Most of the plants died but a certain number produced weak wilted shoots. Root regeneration was found to be practically impossible due to the lack of reserve materials in the young roots. In another plot, plants with larger roots, when cut back at a later period, shot normally. These experiments have been repeated several times since with similar results.

Another method of producing wilt is to cut back tall August sown plants during the cold season, when the temperature of the soil is too low for root regeneration to take place easily. In December 1918, a number of lines of very healthy well-developed August sown plants were cut back when over five feet high. It was found the following February that the new growth exhibited all stages from healthy to wilted foliage. Counts were made on February 17th, 1919, with the following results (Table III).

TABLE III.

Effect of cutting back indigo in the cold weather.

No. of row	No. of plants cut back	Badly wilted	Partly wilted	Normal
1 ..	205	31	72	102
2 ..	176	50	47	79
3 ..	136	46	36	54
4 ..	124	35	30	59
TOTAL ..	641	162	185	294

Thus more than half the plants cut back developed wilt.[1] A number of root washings were made and in all cases wilt was found to be associated with the practical absence of root regeneration. These plants were kept under observation till April, by which time a remarkable change had taken place. The rise in the soil temperature in March and the improvement in the aeration of the soil caused the wilted plants to recover: root regeneration took place and the growth became normal.

Perhaps the most interesting case of the artificial production of wilt took place during the rains of last year. At the beginning of the monsoon of 1918, Java indigo was grown in two sets of lysimeters. These were air-tight cemented tanks 1/1000 of an acre in area, four feet high, built about the ground level and provided with drainage openings which could be closed at will. In one set, alluvial soil obtained from the Kalianpur farm near Cawnpore was used, in the other set, light Pusa soil was employed. Kalianpur soil is exceedingly rich in available phosphate (0·318 per cent) while Pusa soil, when analysed by Dyer's method, gives very low figures for available phosphate (0·001 per cent). The results obtained may be summed up as follows :—

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[1] The plants which developed wilt were those which had their laterals near the surface, the deeper-rooted plants produced normal growth. Thus the monsoon results are reversed during the cold weather. The explanation is simple. In the cold weather, the factor which checks root regeneration is low soil temperature. This affects surface-rooted plants much more than deep-rooted types.

(*a*) In both Pusa and Kalianpur soil, the indigo in the lysimeters with free drainage escaped wilt.

(*b*) When the drainage openings were closed and waterlogging from below took place, all the plants were wilted in both Kalianpur and in Pusa soil.

(*c*) The wilt in Kalianpur soil (rich in available phosphate) was much worse than in Pusa soil (said to be low in available phosphate).

(*d*) The growth in Kalianpur soil was much slower than in Pusa soil.

Recovery from wilt. Cases of complete recovery from wilt occur frequently. Good examples occurred during the rains of 1919. As previously mentioned, wilt first made its appearance this year between July 23rd and August 7th, and again during the first three weeks of September. After the first attack, which was slight, it was observed that plants frequently recovered and after showing wilted foliage produced normal shoots. The roots of two plants which recovered from wilt were exposed on August 21st, and were found to have produced numerous new healthy roots. This regeneration was evidently due to improved soil conditions. In one of the two cases examined, a branch, which showed wilted foliage, continued to grow in length and to form healthy leaves. This does not often occur in cases of recovery. As a rule, the wilted branches die and new healthy shoots are produced.

A second interesting case of recovery from wilt on the large scale occurred in March, 1919, in the case of two plots, which were badly affected at the end of the previous monsoon. Both plots, however, showed a remarkable recovery in March and April 1919. The diseased plants commenced to grow and the shoots and roots formed were perfectly healthy. Similar results were obtained in a plot of Type 15, which had yielded two heavy crops of leaf during 1918. Many of the plants were attacked by wilt during the cold weather of 1918–19, but there was a remarkable recovery in March and April of 1919. The new growth was abundant and healthy and so vigorous were some of the individuals that they survived the monsoon of 1919, and at the present time, October 1919, promise to give a second seed crop.

The most striking cases of recovery from severe attacks of wilt occurred in the lysimeter experiments of 1918. In two cases, in lysimeters which had been waterlogged from below during the rains and in which all the plants were exceedingly badly wilted, complete recovery took place in March 1919, when the stunted diseased individuals which had been looked upon as dead, threw out vigorous healthy shoots.

Conclusions.

These are the facts relating to the occurrence and production of wilt so far as they have been ascertained under Bihar conditions. The conclusion is irresistible that the trouble results from the destruction of the roots and nodules under circumstances when regeneration is impossible. Under estate conditions, the indigo crop, with very rare exceptions, does well till the first cut. This operation, however, destroys the fine roots and nodules, and before new growth can take place root regeneration is necessary. If the soil aeration is sufficient at this period, the plant shoots well and, provided these conditions continue, as in 1919, an excellent second crop follows. If, however, at the time of the first cut, floods cause the ground water to rise and if heavy rain waterlogs the surface soil for long periods, root regeneration is very difficult and the result is wilt and a poor second cut. The wilt which often attacks old indigo in November and December is due to the fact that this plant has been forced to develop surface roots in the late rains. These suffer from want of water as the ground dries after the monsoon and the advent of the cold weather prevents the formation of more roots.

Confirmatory evidence.

If our view of the cause of wilt is correct and if the aeration of the soil is really defective in Bihar during the second half of the rainy season, several consequences naturally follow. Firstly, wilt should not be confined to Java indigo, but should affect other deep-rooted plants while surface-rooted species, on the other hand, should escape. In the second place, as two rainy seasons in India are never the same and long breaks occur, soil aeration in Bihar in August and September should occasionally improve and lead to the recovery of wilted plants and to greatly increased crops of indigo. In the third place, indigo wilt should not occur *in other localities* provided the soil ventilation is efficient during the whole of the monsoon phase. Confirmatory evidence has been obtained in all these directions.

Wilt in Bihar during the monsoon is by no means confined to Java indigo. It is common on many deep-rooted varieties of *patwa* (*Hibiscus cannabinus* L.) and *sann* (*Crotalaria juncea* L.) while shallow rooted types of these two species are little affected. Further, surface-rooted species like Roselle (*Hibiscus Sabdariffa* L.) thrive no matter how wet the monsoon may be. The differences between the distribution of the roots of Roselle and of deep-rooted types of *patwa* are shown in Fig. 3, while in Fig. 4 the roots of an early and late type

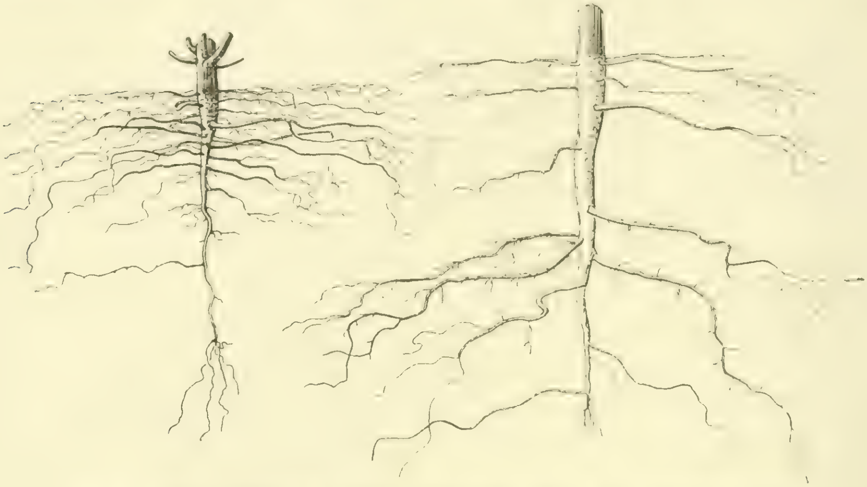

FIG. 3. The root-system of *Hibiscus Sabdariffa* (left) and *H. cannabinus* (right).

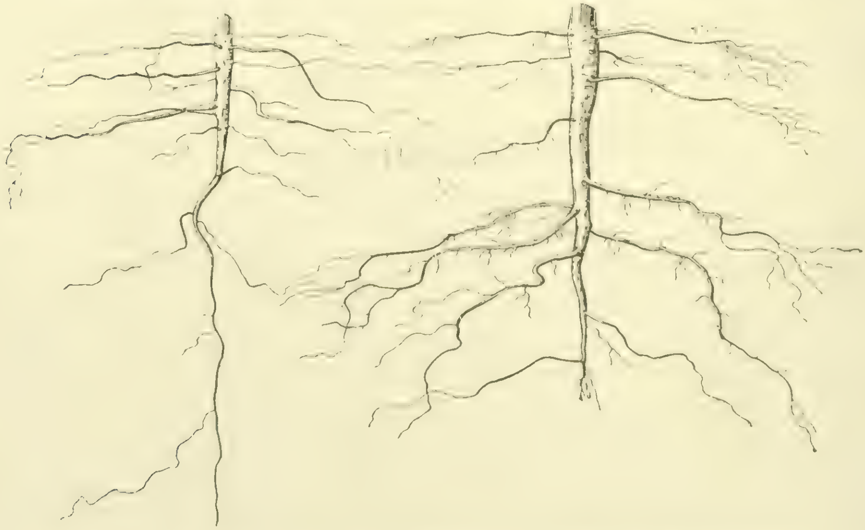

FIG. 4. Early (left) and late (right) types of root-systems in *H. cannabinus*.

of *patwa* are illustrated. The surface-rooted Roselle crop and the early types of *patwa* do well at Pusa even when the soil is waterlogged. The deep-rooted types of *patwa* in such seasons, on the other hand, suffer severely from wilt. Similar results are obtained in the case of *sann* varieties. The local Bihar variety with surface roots sets seed but the deep-rooted tall variety from the

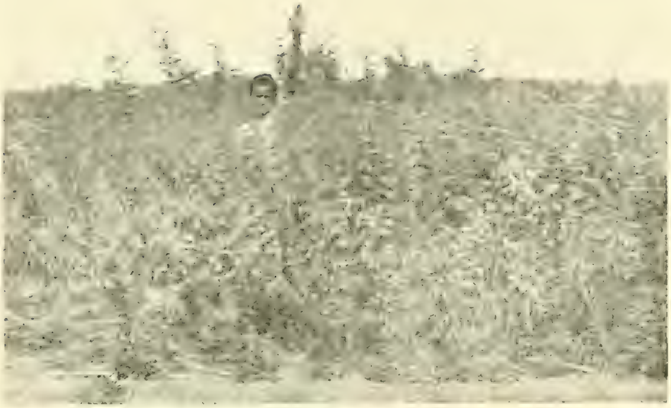

Fig. 1. INDIGO ON BHATA.

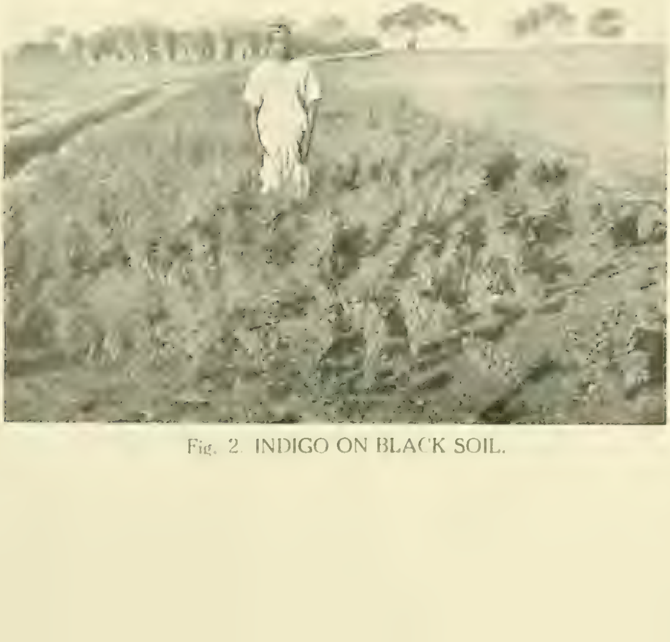

Fig. 2. INDIGO ON BLACK SOIL.

black soils of the Central Provinces suffers from wilt and hardly yields any seed. Thus the deep-rooted varieties of *patwa* and *sann* behave exactly like the deep-rooted varieties of Java indigo and are severely attacked by wilt in the late rains. Roselle and the shallow rooted types of *patwa* and *sann* on the other hand escape wilt.

The general experience of 1919 affords considerable support to our views on the cause of wilt in indigo. For several years past, the rainfall has been heavy and floods have been the rule. Indigo has not done well and wilt has been common. The year 1919, however, was a year of short rainfall combined with the absence of floods. In consequence, the rise of the subsoil water was not considerable. The soil aeration was, therefore, above the average. Slight wilt occurred on two occasions only but the plant rapidly recovered. Three cuts of indigo were obtained at Pusa and the old plant is now exceedingly healthy after the rains. Many of the Bihar estates, particularly those which are most liable to waterlogging, did remarkably well in 1919, and for the first time for many years have reaped an excellent second cut. Although the area under indigo in Bihar in 1919 was 14 per cent less than in 1918, the outturn is expected to be greater than in 1918. Such a result would not be possible if the Bihar soils are suffering from depletion of one of the essential constituents of the soil solution.

Indigo wilt is not met with during the rains in India on porous soils where the aeration is efficient. This interesting fact has been studied in two cases—at Dehra Dun in the submontane zone and at Chandkhuri in the Chattisgarh Division of the Central Provinces. At Dehra Dun, the monsoon rainfall is very high, often more than 100 inches. At the Harbanswala Tea Estate, where Java indigo was grown for some years, there is excellent surface drainage and the soil is remarkably porous, so permeable in fact that it is possible to walk over the fields a few hours after five inches of rain have been received. Here Java indigo grows with great rapidity, the plants are at least ten feet high and no signs of wilt can be detected. At Chandkhuri near Raipur in the Central Provinces, the results were similar. Grown on the porous laterite soils (*bhata*) under a maximum rainfall of over 60 inches, Java indigo thrives remarkably and no trace of wilt is to be seen[1]. Good crops of seed are produced although the soil is particularly poor in total and available phosphoric acid. When grown on the stiff and poorly aerated but richer black soils under similar rainfall and similar climatic conditions, Java indigo develops much more slowly, (Plate V).

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[1] Clouston, D. and Padmanabha Aiyar, A.R., *Agr. Jour. of India*, Special Indian Science Congress Number, 1918, p. 89.

III. THE DEGENERATION OF JAVA INDIGO IN BIHAR.

It has been shown above that wilt during the monsoon phase in Bihar is due to the destruction of the fine roots and nodules at a time when regeneration is difficult on account of poor soil aeration. This, however, does not explain why the crop gradually became susceptible to wilt and why the soil aeration factor should destroy the crop in say 1914, and should have had little or no effect twelve years earlier. As is well known, the earlier consignments of selected seed obtained from the estates of the Dutch planters in Java gave excellent results. The plants grew well and gave at least three cuts of leaf, followed by high yields of seed. On several estates, the crop behaved as a true perennial and gave cuts of leaf during the second monsoon. Slowly the size, vigour and seed producing power of the crop fell off and wilt made its appearance in the late rains in increasing amounts. By 1914, the area had decreased to 15,000 *bighas*. The progressive degeneration of the indigo crop has been found to be due to a gradual change in the gametic constitution of the crop which has been in progress since Java indigo was first introduced into Bihar. The evidence on which this conclusion is based has been arrived at from an investigation of the methods of pollination and fertilization of the indigo plant, a botanical examination of Natal indigo from which the Java plant was originally developed, a detailed study of the various indigos now grown in Java and of the constitution of the crop as cultivated in Bihar.

Pollination and fertilization.

All the species of indigo we have examined at Pusa, including Natal indigo and the various kinds now growing in Java, rarely set seed under net. The floral mechanism is of the ordinary explosive type designed to ensure crossing. Fertilization in Bihar is almost entirely brought about by insect visitors, the chief agents being two common Indian bees (*Apis florea* and *Halictus gutturosus*). Even in a single generation from self-fertilized seed there is a marked falling off in the size and vigour of the offspring so that both self-sterility and natural cross-fertilization have to be considered in any improvement by selection.

Natal indigo.

Java indigo was originally introduced into Java from Natal, where it was found growing in the wild state. Java indigo, as grown by the Dutch planters, is, however, quite a different plant from the wild indigo of Natal, and is said to have arisen by crossing between Natal indigo and one of the species formerly cultivated in Java. In 1913, through the good offices of the Hon'ble Mr. F. B.

Smith, Secretary for Agriculture to the Government of the Transvaal, the seeds of single plants of the wild indigo of Natal were separately collected in that country for growth at Pusa. The samples were sown separately in lines next to next and the progeny was examined. The rows were remarkably uniform in themselves and there were no great differences to be observed between the various lines. Natal indigo proved to be erect in habit with little branched, green stems and a deep root system. The foliage was somewhat sparse. The reddish stems and leaves and the much branched habit of many of the types found in Java indigo were entirely absent. As regards susceptibility to *Psylla* and wilt, the Natal plant showed far less resistance than the Java cultures growing side by side.

The kinds of indigo now grown in Java.

In 1916, a collection of the various kinds of indigo now growing in Java was obtained through the kind assistance of Dr. Koch of the Buitenzorg Botanical Gardens. These consisted of the following samples—Java-Natal indigo from the Koeto Sani Estate, Java indigo from Soerabaya, Natal indigo from Soerabaya, Bengal indigo, wild indigo, Presi indigo, Sumatrana indigo and *Indigofera suffruticosa*. These were grown at Pusa in plots side by side and their behaviour under Bihar conditions, and after cutting back, was carefully studied. In most cases, the root system was also examined. The range in general habit, in the size of plant, in root development, in the proportion of leaf to stem, in vegetative vigour, in the power of repair after cutting back was very great. Some were perennials and others proved to be annuals. Wild indigo and Presi indigo showed low vegetative vigour and little power of repair after cutting back, behaving very much like Sumatrana indigo. Natal indigo grew like the species obtained from Natal and showed itself to be a deep-rooting perennial, unsuited, however, on account of its deep root development, to Bihar conditions. The sample which most nearly resembled the old Java plant which did so well in Bihar, was the Java-Natal from the Koeto Sani Estate. The examination of the plants raised from these samples showed that there are many types of indigo now growing in Java only one of which was in the least suited to Bihar conditions.

The composition of the Java crop in Bihar.

In 1916, the botanical composition of the Java crop, as grown in Bihar, was examined in detail and compared with Java indigo as it existed in 1905 eleven years earlier. By a fortunate circumstance, we grew several plots of Java indigo at Pusa, in 1905 and 1906, and thus became familiar with the plant which at first did so well in Bihar. To enable the changes in botanical composition which have taken place in recent years, to be understood, some reference to the methods of seed supply in Bihar is necessary. Up to very recent years, the method of raising seed in vogue was to allow the best of the fields to flower after the second cut of leaf was taken in August. This involved the production of seed from plant greatly diminished in vigour, both by the growth of two cuts of leaf and by the unfavourable soil conditions set up by the monsoon. The result was insufficient seed and moreover the wrong type of seed. This arose from two causes. In the first place, the early, rapidly growing types in the mixture flowered in September and early October, when the air was too damp for fertilization to take place. These naturally became suppressed. Consequently, the bulk of seed was obtained from the later deep-rooting types. The method of seed growing, therefore, rapidly altered the botanical composition of the crop and favoured deep-rooting unthrifty types. A shortage of seed resulted which necessitated a considerable amount of importation. At first, this was obtained from Java, not however, from the Dutch planters, who had by this time practically given up indigo, but from the natives who naturally paid no attention either to the type or to selection. It was no surprise, therefore, to find in 1916, that the Java crop in Bihar contained such an extraordinary range of types. It consisted of every gradation between rapidly-growing surface-rooted annuals and slow-growing deep-rooted perennials. The range in the type of foliage and in the proportion of leaf to stem was considerable. Weak, procumbent types like the wild indigo of Java, were met with as well as forms resembling Presi indigo. Besides, a host of intermediates occurred which, when sown separately, yielded a wide range of types. Examination of the plants raised from a sample of seed from Java, imported by one of the planters in 1916, showed that the admixture of forms was even greater than that met with in the ordinary Bihar crop. The only conclusion that could be arrived at was that the natives of Java, who for many years had been supplying the Bihar planters with their indigo seed, had been in the habit of growing together all kinds of indigo found in Java and that a great deal of natural crossing had taken place in consequence. In the process, the original type grown by the Dutch planters had become altered almost beyond recognition. The methods of seed growing in Bihar and the entire absence of selection did nothing to improve matters.

These facts and observations fully explain the degeneration which has taken place in Java indigo. While continuous selection was practised by the Dutch planters a type of plant suitable for growth in heavy rice soils was maintained and this seed naturally did well under Bihar conditions and was able to survive the rainy season. The stoppage of selection, the mixing of kinds which is such a characteristic of native agriculture and the resulting crossing with types which do not suit Bihar soon completely altered the botanical composition of the crop and rendered it unsuitable for growth under monsoon conditions. Indigo wilt is, therefore, another example of degeneration through vicinism.

IV. THE REMEDIES AGAINST WILT.

Now that the nature and cause of wilt have been discovered, the question of remedies can be considered. Wilt has arisen from unrestricted natural cross-fertilization which, in the course of time, has completely altered the original type which did so well in Bihar. This crossing with annuals combined with the complete cessation of selection has lowered the general vigour of the crop, has rendered it much more susceptible to waterlogged conditions and has altered the type of root-system. The problem is now to recover by selection the original type which suited Bihar conditions and to *maintain it by continuous selection.* The maintenance of the type will probably prove to be the most difficult portion of the work.

Java indigo only sets seed if visited by bees and the crop is a mass of freely crossing heterozygotes. If grown from self-fertilized seed, there is a rapid loss of vigour through self-sterility. The ordinary methods of selection, therefore, do not apply. Crossing can only be controlled, it cannot be prevented. To maintain the type required, constant selection will be essential and the greatest attention will have to be paid to seed growing. The present practice of importing into Bihar any kind of seed which happens to be offered for sale, will have to be given up and arrangements will have to be made to grow all the seed required locally and to carry out the necessary selection on the estates themselves.

Selection.

A considerable amount of selection work has been done on the ordinary indigo crop and on the samples obtained from Java. Several of these selections have already been tested on an estate scale. Three types have survived the early trials and have been retained for further work. These are as follows :—

Type 10. A mixture of quick growing early maturing forms selected from the seed imported from Java in 1916. The selection work in progress on this type promises to isolate a type of Java indigo which might replace Sumatrana. Sufficient seed has already been obtained for trials on an estate scale which have been arranged for.

Type 15. This is a somewhat bushy indigo with surface roots which shoots well after the first cut and which seeds well in Bihar. It is now being grown successfully on several estates and is being further improved by selection at Pusa.

Type 20. This has been selected from the Java-Natal indigo obtained from the Koeto Sani Estate in Java. It is a tall rapidly growing perennial indigo which resembles the original Java-Natal first introduced into Bihar. A number of plants of the original sample have given two crops of seed and have survived the intervening monsoon. Selection is in progress on this type by which the vigour is being increased and by which the power of repair after cutting back is being improved.

As the soil conditions of the various indigo estates in Bihar vary considerably, it is quite possible that one type of plant will not prove to be the most efficient in all cases. The soils of most of the estates in the northern portion of the indigo tract are heavier and moister than those of the south. Different types may, therefore, be required for the various tracts. Should this be found to be the case, it will add considerably to the labour of selection.

Improved drainage.

As poor soil aeration has been found to be an important factor in the well-being of the indigo crop, it follows that any improvement in the general or local drainage of Bihar during the rains would tend to reduce wilt. Regarded in its widest aspect this is a large subject as the efficiency of the local rivers, on which the monsoon drainage is based, depends on the rise and fall of the Ganges, on the area under inundation in Bengal and on the obstructions (in the shape of embankments) to surface drainage in Bihar. The wider aspects of the subject, however, demand attention as there can be no question that the flood level in Bihar is rising and that the damage done to the monsoon crops is increasing. Improvements in local drainage are in many cases possible by the adoption of the Pusa system, a method which has been taken up already on a number of estates.[1]

Appendix.

Variation of CO_2 *in the soil gas from the different plots in the Botanical Area, Pusa, during the period January to November* 1919.

Apparatus and methods employed.

A hole was first made in the plot by means of a half-inch auger. A brass tube (2 feet 3 inches in length, inner diameter 0·6″) sharpened at one end with holes $\frac{1}{8}''$ in diameter on its side every half-inch apart up to a length of 6″ from the sharpened end, was driven firmly into the soil at an angle of about 30°, so that the end of the tube penetrated to a depth of about 12″ from the surface. Three inches of the tube remained outside the soil. The open end of the tube T outside the soil was connected by means of a rubber stopper R and a tap

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[1] *Bulletin* 53, *Agr. Res. Inst., Pusa,* 1915.

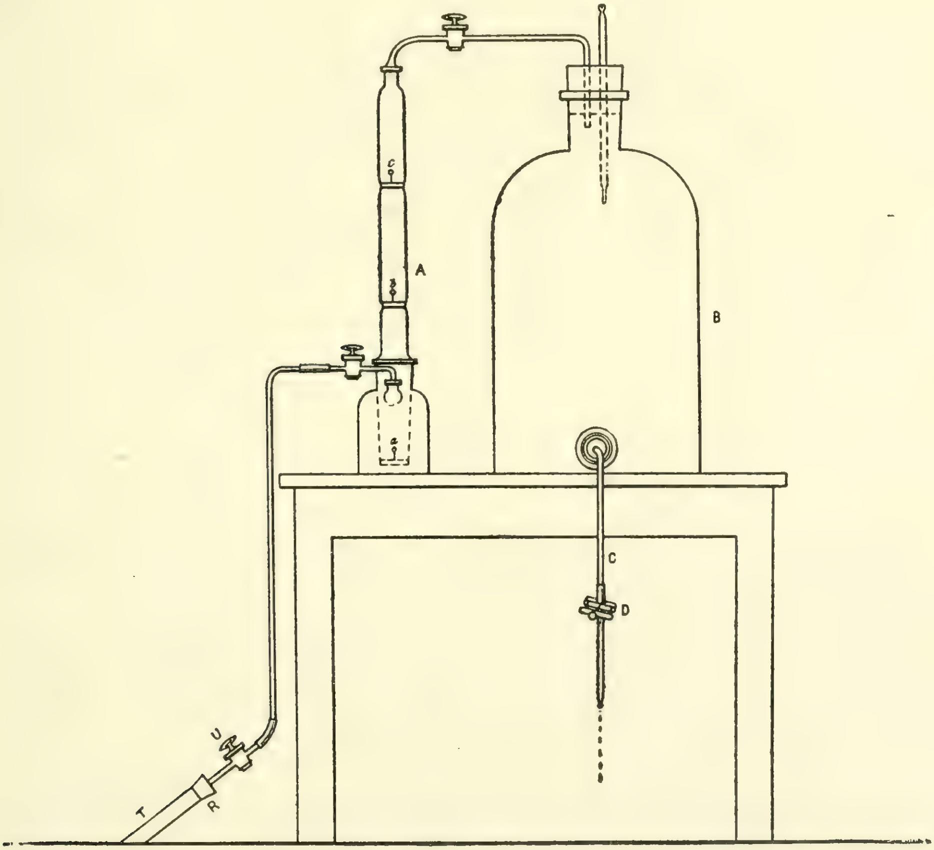

FIG. 5.—Apparatus used in determining the amount of carbon dioxide in the soil atmosphere.

U to a capillary tube V to a Reiset's apparatus A, containing a measured volume of baryta water of known strength. The Reiset's apparatus was connected to a 15 litre aspirator bottle B filled with water. The aspirator bottle was graduated by means of a paper scale to $\frac{1}{2}$ litres. Soil gas was aspirated through the apparatus by allowing the water to flow by means of the exit tube C attached to the aspirator. The flow of the gas was regulated by means of the screw clip D and was kept at about 3 litres per hour. Before opening the tap T all the connections were tested for leakage. On opening the tap T, soil gas passes through the baryta solution which absorbs the CO_2, forming barium carbonate. The three perforated silver cones, a, b and c in the tower of the Reiset's apparatus allow complete absorption of the CO_2 by the baryta solution. About 10 litres of soil gas were aspirated in each case. At the end of each experiment, the volume of gas and the temperature (indicated in the thermometer in the neck of the aspirator bottle) were noted, the tap T was closed, and the apparatus disconnected and brought to the laboratory. The baryta water from the Reiset's apparatus was filtered quickly, filled into a burette, a measured portion run out and titrated against standard acid. The strength of the baryta water used was determined once previous to the aspiration of soil gas and the difference in strength after aspiration gave the measure for calculating the amount of CO_2 contained in the soil gas. By this method, the amounts of CO_2 in the soil gas from (1) grassed down, (2) grassed down but partially aerated by trenches and (3) cultivated plots, were determined once every month and the results obtained are given in Table II and Plate I.

Results.

The results at once show that the CO_2 has been consistently high in the grassed plot and low in the surface cultivated plot; the trenched plot being intermediate between the two as regards CO_2 content. During the first three months, January to March, whereas the grassed plot had shown practically no improvement, the other two showed a marked falling off in the CO_2 present with the lowering of the water-level. During May and June, when the weather was hottest and when the water-level was its lowest, the CO_2 content in all the three plots was also lowest. With the advent of the monsoon and a fair amount of rainfall, all the plots showed a considerable rise in the amount of CO_2 present in the soil gas—the increase being about four times as much in grassed and trenched plots, and one and a half times as much in the cultivated plot. From July to September, coincident with the increase in rainfall and the consequent rise of the water-level, there has been a regular rise in the amount of CO_2 in the soil gas from all three plots. The October and November figures show a marked fall in the amount of CO_2 in all three plots.

November 17th, 1919.

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PART II.

THE FACTORS UNDERLYING THE SEED PRODUCTION AND GROWTH OF JAVA INDIGO IN BIHAR.

I. Seed production.

In 1913, when we took up the investigation of Java indigo in Bihar, the seed problem was acute and the industry was in danger of extinction from this cause alone. The supplies had fallen so low that they were insufficient for sowing while the price had reached a point which seriously reduced the margin of profit.

The method of raising indigo seed in vogue in 1913, was to allow the best of the fields to flower after the second cut of leaf was taken in August. This involved the production of seed from plant greatly diminished in vigour both by the growth of two cuts of leaf and by the unfavourable soil conditions set up by the monsoon. The result was insufficient seed and moreover the wrong type of seed. This arose from two causes. The early, rapidly growing types in the mixture flowered in September and early October, when the air was too damp for fertilization to take place. The bulk of the seed was obtained from the later deep-rooting types. This method of seed growing, therefore, adversely altered the botanical composition of the crop. The shortage of seed which resulted necessitated a considerable amount of importation. At first, this was obtained from Java, where the supply for Bihar was grown by the natives, who naturally paid no attention either to the type or to methods of selection. In recent years, supplies have been purchased from Assam and the United Provinces, and indeed from any locality in India which happened to have indigo seed for sale. The feature of these external seed supplies was the entire absence of selection of forms suitable for Bihar conditions.

The results of our investigation on wilt show that the type of indigo required in Bihar is a surface-rooting, rapidly growing plant which is also resistant to waterlogging. As Java indigo is a mass of heterozygotes and as the range of possible forms is very great, it follows that it is not sufficient merely to isolate a suitable type by selection. The type must be maintained by continuous selection or a repetition of the wilt problem is inevitable. To achieve this object, the seed must be grown in Bihar and the annual selection necessary must be carried out locally. Thus the raising of seed is a matter of the very greatest importance to the future of the indigo industry.

The factors underlying seed production.

The solution of the problem of seed production was found to lie in the growing of a special seed crop and in obtaining the seed from the most vigorous plants. This was accomplished by sowing the seed crop in early August by which time the rains were half over. Provided high lying land in good condition with excellent surface drainage is selected and attention is given to surface cultivation, the seed crop can be established even in the wettest years. At first, growth is slow and root-development is largely confined to the upper layers of soil. As the level of the ground water falls, the soil aeration improves and the roots invade the deeper layers. By October the crop is established and growth then becomes rapid. The yield of seed has been found to depend on two factors—fertilization and the rapid growth of the plant.

Fertilization. The conditions necessary for fertilization were found to be temperature and humidity. In Bihar, indigo can be made to flower at almost any period of the year but it only sets seed if the temperature and humidity are both favourable. In September and early October, the air is too damp for setting to take place and although flowers and pods form, practically no seed is obtained. In December, it is too cold for fertilization.

The best period in the year is the six weeks between October 15th and November 30th, when the weather is warm and dry. At this time, fogs and rain are practically unknown. Bees are very active during this period when, other things being favourable, practically every indigo flower is visited and yields good seed. For all the flowers to be worked over, the plants must be properly spaced and allowed to branch freely. Anything in the nature of overcrowding prevents proper branching and also keeps the air round the plants too damp. It is best, therefore, to grow the crop in lines, about three feet apart, and to attend to spacing in the rows from the very beginning. The plants should be well forward by the middle of October, so that flowering begins about this time. Any great delay means a reduced yield of seed.

Rapid growth. It is obvious that the production of a heavy crop of seed necessitates a large and vigorous plant. This is only possible if the soil conditions are maintained at the optimum. The fields selected must be high lying, above the flood level and the surface drainage must be good. The soil must be rich in organic matter to provide the nitrogen needed for rapid growth and also to preserve the soil texture during the late rains of August and September. After the last showers at the beginning of October, the soil between the rows must be deeply cultivated to supply the roots and nodules with abundant air. Thus organic matter, surface drainage and aeration are the chief soil factors which require attention. The importance of surface drainage needs no proof—in its absence in a wet season there is no crop.

In the investigation of the effect of aeration and organic matter on seed production, a modified method of pot culture[1] was adopted. The pots consisted of pits, 3 feet square and 18 inches deep, filled with soil diluted with various aerating materials or mixed with various manures. The pits thus act as culture pots. If prepared before the rains, the soil settles down and by August are ready for sowing with indigo. In this way, many difficulties are avoided such as the water-supply and the effect of temperature. Periodical measurements of the height are made, determinations of the soil moisture and available nitrogen are carried out and after the seed is harvested, the weight of dry stem, less the leaves, is recorded. The results are set out in Table I.

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[1] *Agr. Jour. of India,* Special Indian Science Congress Number, 1918, p. 36.

TABLE I.

The effect of soil aeration and organic matter on the seed production of Java indigo.

Soil treatment	No. of plants	AVERAGE HEIGHTS OF PLANTS IN CM.											WEIGHT OF DRY PRODUCE IN GRAMMES CORRECTED FOR 50 PLANTS	
		Oct. 10	Oct. 23	Nov. 3	Nov. 13	Nov. 23	Dec. 3	Dec. 13	Dec. 23	Jan. 2	Feb. 1	Feb. 21	Stems excluding leaves	Seed
Control	49	4·4	7·7	11·9	15·5	20·3	24·5	25·9	25·8	26·7	28·1	27·2	68	32
Soil ½ + Sand ½	50	4·3	6·9	11·5	17·4	23·7	28·9	31·6	33·5	34·1	35·6	35·0	127	70
Sodium nitrate @ 8 cwt. per acre ..	50	4·9	8·9	16·0	23·3	30·4	38·3	42·1	43·2	42·7	43·5	42·7	191	115
Soil 7/10+potsherds 3/10 ..	50	4·5	9·2	14·5	19·9	26·6	30·6	33·0	33·9	34·7	34·6	33·5	136	89
Soil 8/10+potsherds 2/10 ..	50	5·2	8·4	13·4	18·1	23·6	28·6	30·4	32·1	32·9	33·6	33·6	141	94
Soil 9/10+potsherds 1/10 ..	49	4·4	7·7	12·5	17·1	22·8	27·4	28·8	30·3	32·4	32·4	31·1	118	92
Soil 7/10+leaf-mould 3/10 ..	50	11·2	23·4	40·8	54·6	70·4	79·3	81·1	82·7	83·2	83·6	83·7	907	577
Soil 6/10+leaf-mould 3/10+potsherds 1/10 ..	50	12·8	25·8	43·3	56·9	67·3	74·4	74·9	77·8	75·8	76·7	76·1	715	685
Soil 5/10+leaf-mould 3/10+potsherds 2/10 ..	49	12·2	24·3	41·1	54·4	66·5	73·7	76·9	77·6	77·6	80·5	78·3	905	595
Soil 4/10+leaf-mould 3/10+potsherds 3/10 ..	50	14·9	28·3	44·7	54·7	67·3	74·2	76·1	75·8	77·6	77·0	76·9	744	511
Control	48	3·8	6·2	9·4	12·3	16·1	19·1	21·0	21·3	23·3	24·3	24·4	72	32

An examination of the table discloses several interesting facts. As regards growth and seed formation, improved aeration by itself has had a marked effect. Seed production was increased nearly three times and growth was almost doubled by the substitution of ten per cent of the volume of soil by potsherds. The replacement of half the soil by sand led to a similar result. The greatest effects, however, were produced by leaf-mould with or without potsherds. The replacement of forty per cent of the volume of the soil by leaf-mould (30 per cen) and potsherds (10 per cent) increased seed production twenty-one times and growth more than tenfold. These results have been frequently confirmed both in the field and in other series of pot cultures. The effect of temperature is shown by the falling off in the rate of growth which took place in all the pots after the end of November, no matter what the treatment. This always happens in the case of Java indigo at this time. After the end of November, no matter what the size of the plant may be there is practically no growth and no setting takes place during the cold months of December, January and February unless the temperature is much above the normal.

An improved method of seed growing.

The discovery of the factors underlying seed production enabled us to devise an improved method of growing indigo seed in Bihar. Instead of raising seed after leaf from a partially exhausted plant, it was found better to reverse the process and to raise a special seed crop which afterwards could be kept for leaf. For this purpose, the seed is sown early in August on specially selected high lying fields, known as *dee* fields. These fields must be above the flood level and they must have excellent surface drainage. They should lie, if possible, near the banks of rivers so that the aeration of the soil is improved as quickly as possible when the water-level falls in September and October. To enable rapid growth to take place and to preserve the soil texture during the rains of August and September, the land must be well manured the previous May or June, with decayed organic matter and afterwards worked as a clean fallow. The crop should be sown in lines about three feet apart and particular care must be taken during the rains to break the surface crusts formed by rain as often as possible. This frequent harrowing is essential as the seedlings of Java indigo are very susceptible to poor soil aeration and are easily killed by surface crusts. After the last rains at the beginning of October, a final harrowing is necessary, followed by deep cultivation between the lines to provide copious aeration for the intense nodular development then in progress.

In addition to correct soil management, the object of which is to raise a large strongly growing plant by flowering time in mid October, particular attention must be paid to thinning and selection. A good deal of natural selection takes place by the extinction, through poor soil aeration, of many of the deep-rooted constituents which naturally result from the gametic constitution of the crop. It is always found that many of the deep-rooted unthrifty plants either die out altogether or lag behind the surface-rooted types. All small weak plants which survive should be destroyed from time to time, and the crop at flowering time should consist only of the type required. The best plants are those which branch copiously and which also flower early. After flowering has set in, a final thinning is required to eliminate those individuals which, although of suitable habit, show a tendency to flower too late.

The result is a magnificent crop of seed which in good years weighs out well over half a ton to the acre. Even in the worst years at Pusa, the yield has not fallen below a quarter of a ton to the acre. The seed produced is heavy and well matured and far superior to anything produced elsewhere. It germinates strongly and evenly and the resulting crops do well. As the yield of seed varies considerably with the season, estates should hold about half their annual seed requirements in reserve so as to make up for any deficit in a year of late floods. Indigo seed retains its germinating power for several years if thoroughly dried before storage in the air-tight seed bins devised by the Botanical Section at Pusa which are now on the market in India.

This improved method of seed growing has been successfully adopted on several of the indigo estates in Bihar and during the present year 1919, excellent crops are to be seen. August sowing in Bihar will by itself improve the type of indigo as it helps to eliminate the deep-rooting unthrifty types susceptible to wilt and favours the shallow rooted quick growing wilt resistant forms. Hence the importance of producing all the indigo seed required in Bihar itself and the discontinuance of the practice of importation from outside sources where natural selection does not operate to anything like the same extent.

II. The growth of Java indigo.

While the investigation of the wilt disease and of the factors underlying seed production were in progress, attention has been devoted to the conditions necessary for the growth of the ordinary indigo crop. A large amount of work has been done on this side of the question and several improvements in cultivation have resulted. The growth of the indigo crop, other things being equal, has been found to depend mainly on two factors—soil aeration and organic matter.

Soil aeration.

From the time the ordinary crop is sown in September or early October to the following May, indigo shows a remarkable response to soil aeration. After germination and while the seedlings are small, anything in the nature of a surface crust is fatal and constant harrowing is essential. During the cold weather and the hot months of March, April and May, indigo shows a remarkable response to repeated harrowings with the lever harrow. These implements were originally introduced into India by the Botanical Section of the Pusa Institute and are now widely used on the indigo estates. They enable the surface soil to be broken up to a depth of nearly two inches and the mulch produced preserves the soil moisture during the hot weather. In addition, aeration is improved and the large supply of air needed by the intense nodular development which takes place at the break of the rains, is provided for. During the early monsoon, soil aeration is maintained by the rainfall which is a saturated solution of oxygen and experiments show that cultivation at this period is unnecessary and does more harm than good. In the later rains, the marked aerotropism of the roots (caused by the rise of the gases of the deep soil layers which follows the upward movement of the ground water) combined with the destruction of the absorbing root system of the subsoil, places cultivation out of the question. This should, therefore, stop at the break of the rains in May.

In addition to improved aeration by means of surface cultivation, the indigo plant shows a marked response to a more open soil texture and also to the aeration of the subsoil. As an example of the effect of altered soil texture the results obtained on growth by the addition of sand or potsherds to the soil are of interest. (Table II.)

Table II.

The effect of improved soil aeration on the growth of indigo.

Kind of soil	No. of plants measured	Average length in cm.	Percentage increase
Soil only	33	36·7	..
50% soil 50% sand	36	51·6	40
90% soil 10% potsherds ..	33	48·3	31
70% soil 30% potsherds ..	35	50·9	38

The substitution of only ten per cent of the volume of soil by inert potsherds sufficed to increase growth by over 30 per cent.

Equally striking are the results obtained by waterlogging the subsoil before the indigo crop is sown. The effect of waterlogging the heavier soils at Pusa during September, has been found to result in extensive losses of nitrogen through denitrification. In September 1917, a somewhat stiff piece of land was waterlogged for a month and sown with Java indigo the following October. The effect of the waterlogging on this leguminous plant was very marked. Five months after sowing, equal areas on the waterlogged and control plots were taken and the heights of the plants were measured. On the waterlogged plot, the average height of 200 plants was 10·5 cm. ; on the control, the average height of an equal number of plants was 28·0 cm. When the root system of the plants on these plots was examined, it was found that the first effect of waterlogging was to restrict the roots to the upper layers during the first few months of growth and to change the general character of the root system. The results are shown in Fig. 1. On the left is represented the root system of a plant from the plot waterlogged a month before sowing, on the right a specimen of the roots from the control plot is to be seen. In the waterlogged plot, the development of the tap-root is arrested and one of the laterals after bending takes its place. In the case illustrated, the acting tap-root was followed to some distance and was found to give off very few branches.

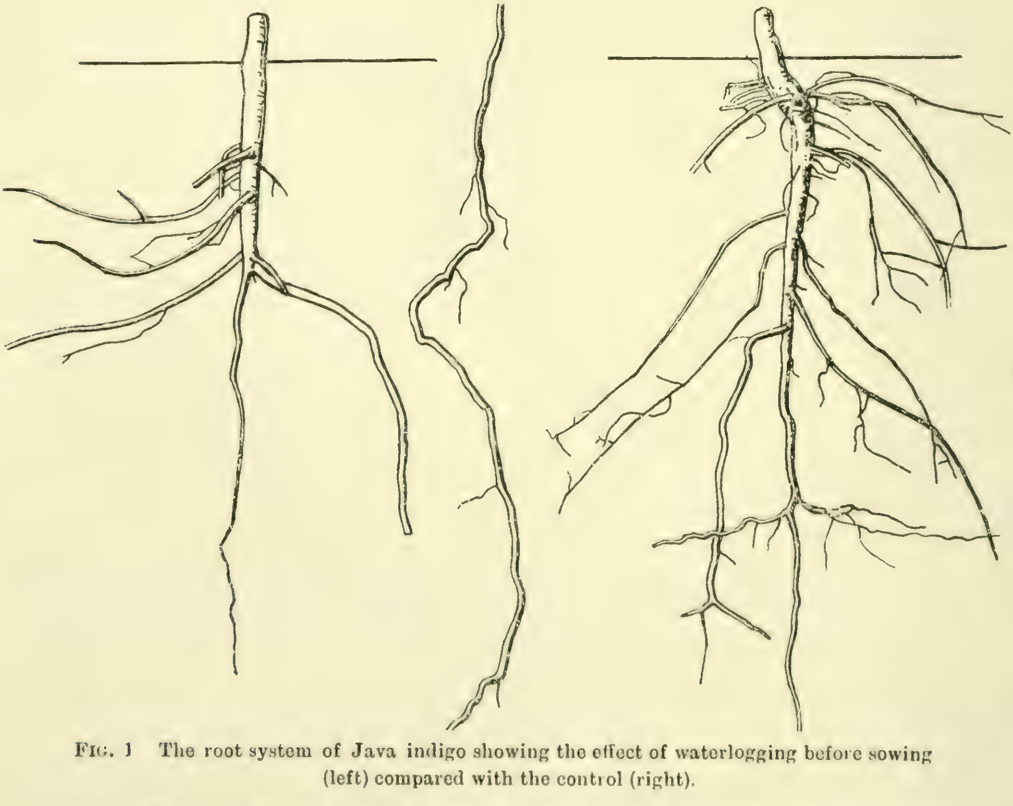

FIG. 1 The root system of Java indigo showing the effect of waterlogging before sowing (left) compared with the control (right).

When the subsoil is gradually waterlogged from below after the seed is sown, still greater changes in the root system are obtained. Gradual waterlogging from below after sowing is obtained by growing the crop in lysimeters, the drainage openings of which can be closed at will. In 1918, a series of such experiments was carried out and at the end the growth and root-development obtained under drained and waterlogged conditions was compared. The results are shown in Fig. 2.

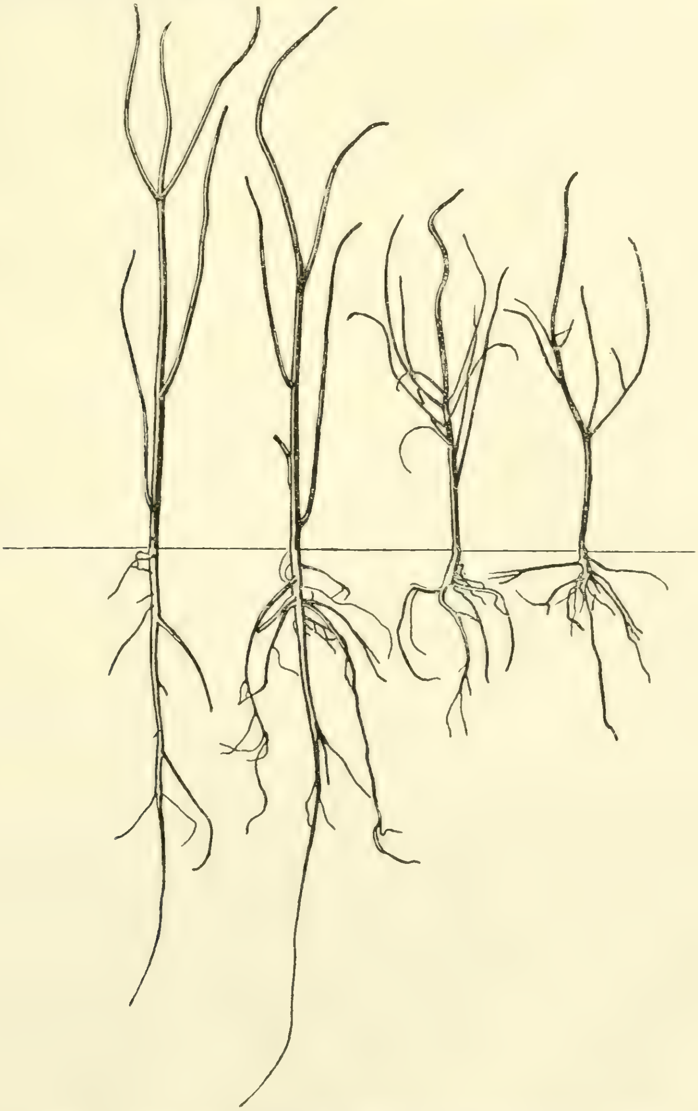

FIG. 2. The effect of waterlogging after sowing on the root-development of Java indigo.

Manuring.

Although indigo is a leguminous plant there is a copious development of nodules only after the early rains, so that it responds markedly to nitrogen applied in the form of organic matter such as leaf-mould, farmyard manure or oilcake. That nitrogen is required by the young crop is suggested by the waterlogging experiment carried out in September 1917, which is described above. This indication has been confirmed by the results of numerous field experiments and of several series of pot cultures. The chief effect of the organic matter is to stimulate the seedlings and to help the crop to establish itself. If the soil is too poor at sowing time, numerous bare patches in the field develop and the crop looks thin and starved. Organic matter, on the other hand, leads to dark foliage and to strong growth. The effects persist till the break of the rains when they pass off due, in all probability, to the result of the intense nodular development which is such a feature of the crop at this period. Even during the rains, the indigo crop appears to make use of combined nitrogen as the cereal crops like wheat and oats which follow indigo compared with those on fallow land never show any great vegetative vigour and exhibit all the signs of a reduced supply of available nitrogen.

The effect of available phosphate on growth has been investigated by growing indigo in two sets of lysimeters—one filled with alluvial soil from Kalianpur and the other with Pusa soil. Kalianpur soil is exceedingly rich in available phosphate (0·318 per cent) while Pusa soil, when analysed by Dyer's method, gives very low figures (0·001 per cent) for available phosphate. In spite of this the growth has always been greater in Pusa soil than in Kalianpur soil as the following measurements taken on September 11th, 1918, show :—

	Average height of plants in inches.
Pusa soil	10·7
Kalianpur soil	5·0

A second similar set of measurements were made on September 15th, 1919, with the following results :—

	Average height of plants in inches.
Pusa soil	36·4
Kalianpur soil	20·1

These figures afford no support to the view that manuring with superphosphate will increase the growth of Java indigo.

PUSA :
20th November, 1919.

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January 1921. Botanical Series. Vol. XI, No. 2

Memoirs of the Department of Agriculture in India

STUDIES IN DISEASES OF THE JUTE PLANT

(1) DIPLODIA CORCHORI SYD.

BY

F. J. F. SHAW, D. Sc. (Lond.), A.R.C.S., F.L.S
Second Imperial Mycologist

AGRICULTURAL RESEARCH INSTITUTE, PUSA

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BY
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January 1921. BOTANICAL SERIES. VOL. XI No. 2.

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Second Imperial Mycologist.

[Received for publication on 23rd January, 1920.]

The Disease in the Field.

During the summer of 1917[1] an area of about 40 acres on the Pusa Farm was placed under jute (*Corchorus capsularis*). The variety grown was "kakya bombai," a pure line race selected by the Fibre Expert to the Government of Bengal (Mr. R. S. Finlow) and possessing many advantages in size and yield over the races commonly grown by the ryot in the great jute-producing districts of Eastern Bengal. Not all the area under jute was sown at the same time, some being sown about the middle of March and the remainder not until June. As the season advanced, the superior height and thickness of stem of the early sown portion became very noticeable. In the case of jute grown for seed, however, the size of the stem is not of such importance as when it is grown for fibre.

By the beginning of August the early sown portion of the crop had reached a height of 10–12 feet, about twice the size of the late sown, and presented a dense and almost impenetrable growth. The plants were a bright green colour but throughout this portion of the crop several plants appeared to be drying up and wilting, with the formation of a dense black discoloured band round the stem at a point about 2–3 feet above the ground level (Pl. I, fig. 1). Such plants ultimately lost all their leaves and were left standing as dry black stems, forming relatively conspicuous objects among their healthy green neighbours. Intermediate stages in the progress of the disease showed that the blackening of the stem nearly always commenced with the formation of a discoloured ring or band

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[1] *Scientific Reports of the Agricultural Research Institute, Pusa*, 1917-18, page 74.

round the stem which gradually increased in density and spread up and down the stem. Hence the suggested name of "black band" disease. Jute plants, as the crop is grown in the field, consist typically of a long straight stem which remains unbranched until near the apex where the flower-bearing axes arise. Such a stem has numerous lateral buds throughout its entire length and from these buds abortive branches often arise. These branches reach a length of 2–4 inches and then almost invariably cease growth and dry up; they remain as short brown twigs projecting from the main stem. It is noticeable in the field that the commencement of an infection is frequently from the base of one of these lateral twigs, where the dead tissues might be expected to afford an exceptionally favourable medium for the commencement of fungal growth. In other cases a leaf, or a lateral bud with leaves just open, is seen in a collapsed and blackened condition adhering to the main stem, and the disease appears to have spread from this point. As the disease extends on the main stem the bark splits longitudinally (Pl. 1, fig. 2) and the bast fibres are exposed. In the final stages the fibres can be seen brown and dry with the intervening tissues decayed away. Examination of the surface of a blackened stem showed the presence of minute spherical black bodies (Pl. 1, fig. 3), suggesting pycnidia, and frequently there were visible, even to the naked eye, small white aggregations, which appeared to be exuding from the spherical black bodies. On rubbing the hand up and down such a stem the fingers became covered with a black dust.

As the season advanced the number of infected plants rapidly increased until by the middle of October about 20 per cent. of the early sown crop was infected. The late sown crop remained small, about 6 feet high, and was surprisingly free from the disease—not one infected plant could be discovered. In addition to the jute seed crop at Pusa a quantity was being grown in neighbouring indigo factories for seed for the Fibre Expert. These crops all showed the same state of affairs as the Pusa crop. Where the jute had been sown early, and the plants were well developed and comparable in size to the early sown jute at Pusa, there the same disease was found; crops, however, which had been sown late, and were small in stature were free from the disease. A similar result followed from the inspection of the jute seed crop at more distant centres in Champaran.

In addition to the jute seed crop in Bihar, a further area was being grown for seed on an estate in Kamrup, Assam. The inspection of the Kamrup crop provided some very interesting information. On this estate jute (green *C. capsularis*) was extensively grown and the bulk of the crop was being cut for fibre, but an area, estimated to yield 1,000 maunds, was being kept for seed. In growing a crop for fibre the main consideration is to secure long straight unbranched stems which will give a good length of fibre. In growing a crop for seed the branching of the main stem should be encouraged in order to increase the number of potential flower-bearing axes. Bearing these factors in mind the crop at Kamrup consisted of a thickly sown portion, in which the plants had grown up almost touching one another and which was being cut for fibre, and an area in which the plants had been thinned out to a distance of 18 inches and which was being kept for seed. All the jute was " kakya bombai " and in both cases the stems had reached a height of about 10 to 12 feet. In the case of the thinned out seed-crop, however, the stems were rather thicker and of course more branched than in the fibre crop. This seed crop showed many cases of the disease in a fashion precisely similar to the Pusa crop. In the fibre crop, however, diseased individuals were much less numerous, and in fact the trouble would more or less have escaped notice and would not have been classed as a disease in this crop. A further correspondence with the facts observed in Pusa was furnished by two seed plots which had been sown on 21st June, a month later than the remaining seed and fibre crops. These plants were much smaller than the earlier sown plants and the disease was not established among them. In one corner of one of these plots, however, the plants had grown to an exceptionally large size, possibly owing to some local richness of soil, and here about 30 per cent. of the plants had the disease. The yield of seed from diseased plants is very greatly reduced, as such plants dry up quicker than their healthy companions and are liable to shed their seed in the field. The actual formation of seed in the capsules also appeared to be less than normal.

Thus the yield of seed per acre in the Assam plots was 5 maunds in 1917 in comparison with 7 maunds in 1916, and at Pusa the yield was 4·33 maunds in 1917.

In 1918[1] jute was again grown on the Pusa Farm but the incidence of the disease was much less, save in one field which had been under jute in 1916. Here the crop was so badly diseased that the whole area had to be cut and burnt. The fact that it is only stems of a certain size and maturity which are liable to infection was well illustrated by some statistics obtained from this crop. Of stems over 5 feet high a proportion of about 20 to 25 per cent. was infected and the same amount of diseased plants was observed on counting only stems which were 1 inch, or more, thick at the ground level. In any jute crop, however, there are a considerable number of plants which are the result of late germination and in which the stems remain thin and relatively short. Among stems of this size the disease was practically non-existent, and if such plants are included in the estimation the proportion of diseased stems may be as low as 3 per cent. The proportion of diseased stems among the larger plants, however, gives a more accurate measure of the extent of the damage to the crop.

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[1] *Scientific Reports of the Agricultural Research Institute, Pusa*, 1918–19, page 69.

In Bihar, in 1918, the disease was generally much less than in the preceding year. This is probably to be attributed to the abnormal dryness (Plate VIII) of the air during September--October, when the disease is apt to spread most quickly. In all cases it was found that the late sown crop was relatively immune and the early sown, large, well grown crop was most liable to the disease.

In Eastern Bengal, in August–September, 1918, the disease was present in Dacca, Mymensingh. Sinjhani and Haldibari. The number of diseased stems, however, was very small, and unless the disease appears earlier it is evidently not likely to be a serious source of damage to the fibre crop. An interesting fact observed was that in Dacca red-stemmed varieties of *C. capsularis* appeared to be much less susceptible to attack than green-stemmed, while *C. olitorius* appeared to be quite free from the disease. In Rajshahi the jute crop was *C. olitorius* and here also the disease was practically absent.

In 1919 the condition of the jute crop on Dacca Farm by no means agreed with that in the previous season. The *olitorius* crop, both green and red-stemmed varieties, was attacked. The incidence of the disease was not heavy and varied considerably in different fields on the farm, the greatest damage seen in any one area was probably about 10 per cent. Red-stemmed *C. capsularis* was also attacked. These observations were quite sufficient to show that neither red-stemmed *capsularis* nor *olitorius* jute was resistant to the disease. At Chinsurah Farm the jute crop was *C. olitorius*, both red and green varieties being the same as at Dacca. The crop was in this case very fine, averaging about 14 feet in height, and there was not a single case of " black band " disease. At Rangpur Farm both the *olitorius* crop and green-stemmed *capsularis* were infected. The disease, however, only reaching an appreciable degree when the plants were of a certain size.

In Bihar, in 1919, the state of the jute crop was very similar to that in 1918. A considerable portion of the seed crop had, however, been sown as late as June and this was invariably clean and healthy. In the more early sown areas the crop was only slightly diseased and not to an extent which would seriously diminish the yield.

Reviewing these observations on the seed jute crop of the last three years certain general facts emerge :—

(1) The disease exists in Bihar, Assam and Bengal, and is evidently well diffused over the whole jute-bearing area.

(2) The incidence of the disease is in some way bound up with the crop reaching a certain degree of size.

Beyond these facts, however, the evidences as to the conditions which favour the increase of the disease are confusing and will be considered later.

The Cause of the Disease.

A microscopic examination of a diseased stem demonstrated the presence of a parasitic fungus. The small black spherical bodies visible just below the epidermis were the pycnidia of a *Diplodia*, and the black dust which comes off on handling a diseased stem was *Diplodia* spores. The small white aggregations which appear on the surface of a diseased stem are masses of immature hyaline *Diplodia* spores. The spores when mature are dark brown, bicellular bodies averaging $24 \times 12\mu$ within the limits $20–29\mu \times 10–15\mu$. The pycnidia were rounded black structures, about $200–300\mu$ in diameter, with a conspicuous mouth (Pl. II, figs. 1, 2) : although numerous and almost touching they do not run together. This fungus is evidently identical with that previously described[1] by Sydow and Butler as *Diplodia Corchori* Syd. and first identified from material collected in 1910. Earlier than this the fungus had been collected, but not identified and named, from a wide area in Bengal including places as far as Kissenganj and Mymensingh. It has, however, never before 1917 been observed in such numbers as to suggest that it was anything but a stray parasite.

On splitting open the bark of a diseased stem the surface of the wood is found to be coloured a deep brown, and in advanced cases of disease is almost black. This discoloration is due to the presence of masses of dark brown hyphæ of *Diplodia* running over the surface of the wood. The fibre is similarly stained.

A transverse section of the stem shows that the pycnidia are very superficial and occur in the outer layers of the cortex just covered by a few layers of cork cells (Pl. II, fig. 1). The mouths of the pycnidia break through this cork covering. The hyphæ of the fungus ramify in the cortex and traverse the phloem in all directions ; they can frequently be seen following the course of a medullary ray as far as the cambium, where hyphæ are particularly numerous, and in fact this tissue seems to afford a peculiarly favourable medium for the growth of the fungus. This accounts for the discoloration of the outer surface of the wood in more advanced cases of disease. Hyphæ also penetrate into the wood and are easily visible in section in the cells of the xylem.

From diseased plants the spores of the fungus were obtained and germinated in pure culture. In culture the fungus forms a copious mycelial growth, the mature hyphæ being a dirty greyish colour merging into brownish black in the old cultures. Up to the present pycnidia have not been formed on artificial media but on the cellulose medium and on dead sterile jute stems papillate stromata were often produced.

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[1] Sydow, H. et P., et Butler, E. J. "Fungi Indiæ Orientalis, Pars V." *Annales Mycologici*, Vol. XIV, 1916, page 196.

In artificial inoculations the fungus sets up a very rapid degeneration in the tissues of the cortex and phloem (Pl. IV, figs. 1, 2). In sections of an early stage of an infection hyphæ can be seen ramifying in all directions in the cortex (Pl. IV, fig. 2; Pl. III, fig. 2), and it is evident that a cellulose dissolving enzyme is being secreted. The cellulose dissolving power of the fungus was tested in cultures upon pure cellulose. A cellulose (parchment) diffusion shell was placed in a flask with 50 c.c. of the following nutrient solution :—

	grm.
Ammonium phosphate	6
Potassium nitrate	6
Magnesium sulphate	1
Lactic acid	2
Water	1,000 c.c.

The interior of the diffusion shell was then infected with the mycelium and the flask placed in an incubator at 30°C. Within 24 hours hyphæ had grown through the diffusion membrane into the surrounding liquid. This penetration could only be the result of the solution of a part of the diffusion membrane by the hyphæ. After two months the fungus had formed a dense mycelial growth both within and without the diffusion shell, which had become quite soft and rotten. Such cellulose fibres as persist among the fungal hyphæ lose the characteristic colour reaction with Schultz solution which is given by the unaltered cellulose. No sugar could be detected in the liquid in the flask. A control flask, which had not been infected with the fungus, remained unchanged.

The fungus was then cultured upon pure cellulose, each culture containing about 0·5 gramme of cellulose and 50 c.c. of the following solution :—

	grm.
Potassium nitrate	10
Monocalcic phosphate	5
Magnesium sulphate	1
Water	1,000 c.c.

In this case the only carbon present in the medium was the cellulose. Three flasks were infected with the fungus and three were kept as controls. After two months, when vigorous growth in the infected flasks had nearly rotted the cellulose, the flasks were opened and the liquids filtered and made up to a volume of 100 c.c. From each liquid 25 c.c. were taken and then acidified with 11 c.c.

concentrated sulphuric acid and titrated with a solution of potassium permanganate (1 grm. in 1,000 c.c.). The liquids from the control flasks required respectively an average of 0·85, 0·75 and 0·85 c.c. of the potassium permanganate solution before a permanent colouration was obtained. For the entire liquid content of each control flask therefore approximately 3·2 c.c. of potassium permanganate solution were required. In the case of the three infected flasks 25 c.c. of the liquid required an average 2·3, 2·2 and 1·9 c.c. of potassium permanganate before a permanent coloration was obtained. For the entire liquid contents of an infected flask, therefore, an average of 8·4 c.c. of potassium permanganate solution was needed. Thus the liquid from the infected flasks had more organic matter in solution than that from the uninfected flasks, and this could only have come from the solution of the cellulose by the action of the fungus.

The power of setting up a rot in cellulose tissues does not, however, explain the manner in which the fungus gains entry into the stem of the host. This can only result from ingress either at some break in the superficial tissues or from direct penetration of the cuticle. An infection in which a minute piece of agar culture was placed on the surface of the stem resulted in direct penetration of the epidermis and cuticle (Pl. IV, fig. 2) within 12 hours (Experiment IX). There exists, however, in this case the possibility that the presence of a small piece of agar in contact with the stem may cause a local softening of the cuticle, rendering the passage of the fungus more easy than under natural conditions. The following experiment was, therefore, carried out with the object of deciding whether the fungus could penetrate the uninjured cuticle. Three glass rods terminating in a small funnel-shaped expansion were placed upright in the soil next to three jute plants so that the edge of each funnel was within 1 m.m. of a stem. A small piece of an agar culture of the fungus was then placed in the bottom of each funnel and the whole enclosed in a lamp chimney plugged with cotton wool. In the moist atmosphere the hyphæ grew out over the edge of the funnel and made contact with the jute stem. A dark stain appeared on the stem in the region of infection, but the plants showed no sign of wilting, and after a week the infections were opened and portions of the stem from the region of apparent infection were fixed for microscopic examination. Sections showed clearly that penetration of the stem had taken place, and scattered hyphæ, causing a local disintegration of the tissues, could be seen in the cortex (Pl. III, fig. 2). Unfortunately in this case cork formation had just commenced, and no cases could be seen in which hyphæ were directly penetrating the cork layers from the outside. The only place at which entry was obvious being in the region of a lenticel. The question, therefore, whether the hyphæ of *D. Corchori* can ordinarily penetrate the uninjured cuticle and whether, if so, they do so by virtue of a special cutin-dissolving enzyme[1] or merely by mechanical pressure, as stated by recent investigators[2] in the case of other parasites, remains to be settled. It cannot be overlooked, however, that in the field the disease could spread rapidly even supposing that the epidermis of the host was impervious to the fungus. An easy point of entry is afforded by the numerous lateral branches which exist as small dry twigs, and it has already been mentioned that, in the field, a number of infections appear to originate in this way.

Inoculations.

Inoculations with pure cultures of *Diplodia Corchori* were first carried out during September, 1917. The plants used for the experiments were healthy jute stems, of the variety "kakya bombai," standing 7–10 feet high, along the eastern edge of the Pusa crop.

Experiment I. Three plants each received a small tangential cut on the stem surface, and the wound was infected with a small piece of agar culture of *D. Corchori*; two of the plants had the wound infections bound up with oiled paper. In each case a brown stain appeared at the seat of infection and spread up and down the stem; pycnidia and spores rapidly developed on the diseased tissues and when the discoloration had completely ringed the stem, the plant withered and lost its leaves. All the plants were dead in from 10 to 14 days after infection, the fungus spreading up and down the stems, which were left standing as blackened sticks.

Experiment II. Three plants were infected with pure cultures of *D. Corchori*, small portions of agar cultures being placed at the base of lateral shoots. These lateral shoots are quite small, about 1–3 inches long, and as a rule do not develop further, but are left on the mature plant as short dead twigs. In one of the plants the point of infection was loosely bound up with oiled paper. Four days after infection the lateral shoots were dead and black and a small brown stain was spreading in the axils of these shoots on each stem. In the case of the infection which had been bound up, the disease spread rapidly up and down and round the stem, as in Experiment I, and death took place about 14 days after infection. Pycnidia and spores of *Diplodia* were abundantly developed and the fungus was re-isolated in culture from these spores. Near the seat of infection, where the fungus was most strongly developed, the bark became cracked and the brown discoloured surface of the wood could be seen. In the other two plants the fungus spread up and down one side of the stem but did not succeed in ringing it, and these plants retained their leaves as long as their healthy neighbours.

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[1] Wiltshire, S. P. "Infection and Immunity Studies on the Apple and Pear Scab Fungi (*Venturia inæqualis* & *V pirina*)." *Annals of Applied Biology*, Vol. I, January, 1915

[2] Blackman, V. H. & Welsford, E. J. "Studies in the Physiology of Parasitism." *Annals of Botany*, XXX, July, 1916.

[2] Brown, W. "Studies in the Physiology of Parasitism." *Annals of Botany*, XXX, 1916.

[2] Dey, P. K. "Studies in the Physiology of Parasitism." *Annals of Botany*, XXXIII, July, 1919.

Experiment III. Three plants were infected with pure cultures of *D. Corchori*, each plant being wounded by means of a tangential cut on the stem surface. These wound infections were all left exposed to the air. Two of the plants died within 10 days, the other was not completely ringed by the disease and survived longer.

As the season was now far advanced and the crop was drying off, further inoculation work was stopped. These preliminary experiments had, however, shown that the fungus was capable of infecting both unwounded and wounded healthy jute stems. Inoculation experiments upon green-stemmed *C. capsularis* were resumed in 1918.

Experiment IV. Two pots were sown with jute on 12th March, 1918, and four young plants were infected from an agar culture of *D. Corchori* on 22nd April, 1918. The pot was kept under a large bell jar; another pot sown at the same time, but not infected, was also kept under a bell jar. The plants in both infected and control pots lost their leaves, from being kept under a bell jar, in five days. The infections did not take.

Experiment V. Five plants, sown in a pot on 12th March, 1918, were infected with a young, 48 hour old, agar culture of *D. Corchori* on 2nd May, 1918. Four of the plants were infected at a leaf base and one on the stem. All the infected plants, and an equal number of uninfected plants were kept under bell jars. All the infected leaves wilted and fell off by 7th May, 1918, and in one case a black stain commenced to spread from an infected leaf base up the stem and a microscopic examination showed that *Diplodia* hyphæ were present. No stem damage was observed in the other case, and by 13th May, 1918, the plants, both infected and control, had become unhealthy from being kept under a bell jar. No definite conclusion as to whether the fungus could infect young jute stems could be drawn from these last two experiments.

Experiment VI. Two plants sown in a pot on 12th March, 1918, were infected from an agar culture, 48 hours old, of *D. Corchori* on 27th May, 1918. The length of stem within which the infection was done was enclosed in a glass lamp chimney, the ends of which were plugged with cotton wool. After 24 hours a brown stain was distinctly visible at the seat of each infection, and by 31st May the discoloration had spread and one plant was nearly ringed; in both plants the leaves were yellowing and falling. Both plants were ringed by a black band by 3rd June, and *Diplodia* pycnidia and spores were clearly visible on the surface of the diseased tissues. One of the plants was completely wilted and dead by 6th June, and an examination a week later showed that *Diplodia* hyphæ had travelled through the cortex and reached the wood; cortex and phloem were practically destroyed all round the stem for a stretch of several inches. The other plant remained green and healthy in its upper part, despite the fact that it also was completely ringed by the fungus at the seat of infection. An examination of the diseased section of the stem showed that the plant had reacted against the parasite and had formed new vascular tissue to one side of, and external to, the old tissue.

Experiment VII. Two plants, sown in a pot on 12th March, 1918, were infected from a young agar culture of *D. Corchori* on 3rd June, 1918. One plant was infected on the stem surface and the other at the base of an axillary shoot; both infections were jacketed with lamp chimneys. A brown stain appeared at the seat of infection in 24 hours, and on 7th June had spread up and down and round the stems with the production of pycnidia. One plant died a few days later but the second survived with the formation of fresh vascular tissue as in the last experiment. Controls remained healthy.

Experiment VIII. Three plants, sown in a pot on 12th March, 1918, were infected from a young agar culture of *D. Corchori* on 7th June, 1918; all the infections were carried out on the uninjured stem surface and were jacketed with lamp chimneys. After 24 hours all infections had taken and a brown stain was spreading over about $\frac{1}{2}$ inch of the stem at the seat of infection. Two of the infections were removed for microscopic work and the third was left standing, its glass jacket being removed on 10th June, 1918. This plant died with typical symptoms of *Diplodia* disease during the next week. A characteristic of the diseased stems in all inoculations, and one which has also been observed in the field, is the longitudinal splitting of the diseased bark by which the surface of the wood is laid bare. In some cases there appears to be an actual separation of the constituents of the bast fibre, and it may be inferred that the fungus has an action upon the tissues which is possibly analogous to that which takes place during retting. Controls remained healthy.

Experiment IX. Two plants, sown in a pot, on 12th March, 1918, were infected on 8th June, 1918, from a young culture of *D. Corchori*. These infections were made at 7 p.m. and were jacketed with lamp chimneys in the usual way. At 7 a.m. on 9th June, 1918, after 12 hours, the infections had taken and a small brown stain was spreading on the stem surface. Both these stems were removed, and the tissues fixed in chrome-acetic, for microscopic examination.

Experiment X. Four plants in pot culture, sown on 12th March, 1918, were infected on 25th July, 1918. These plants were about 6 feet high and 1 inch thick at the base of the stem; the infections were jacketed with lamp chimney. None of the infections took. Small brown stains at the point of infection occurred in two plants but they did not spread, and the plants remained living and healthy. This experiment took place during a period of relatively high temperature.

All the above inoculations (Experiments IV–X) were made from a series of agar cultures which had originated from a spore infection on agar in December, 1917. The possibility of the fungus declining in the virulence of its capacity to infect the living jute stem owing to prolonged growth in artificial culture could not be lost sight of, and a further series of infections from a fresh isolation of the fungus was carried out. The fungus was re-isolated from spores during a visit to Dacca in August, 1918, and infected upon living jute plants in the field. The inoculations were carried out on a small plot which was sown with jute on 5th March, 1918, and the plants subsequently thinned out to a distance of 18″. This crop grew very well and attained a height of about 14 feet; at the time of these experiments it was just over flowering period.

Experiment XI. Infected five plants on 9th September, 1918, as follows :—

(1) A stem received a small tangential wound about 4 feet above ground level and was infected on the wound and the infection bound up with cloth. After 48 hours a brown stain was spreading from the seat of infection and pycnidia were produced and the plant ringed on 14th September, 1918. The plant wilted and died on 15th September, 1918.

(2) A stem was infected on a small tangential wound about 4 feet from the ground level, but the infection was not bound up and was left exposed to the air. The plant was killed by 17th September, 1918.

(3) Two stems were infected, each at the base of a small lateral shoot about 4 feet above ground level, and the infections bound up with cloth. One plant died on 17th September, 1918, but the other never became completely ringed and survived.

(4) One plant was infected at the base of a lateral shoot but the infection was not covered with cloth and remained exposed to the air. The infection spread with the usual symptoms but the plant was not completely ringed and did not die until 18th October. The plants killed in this experiment are shown in Pl. V, fig. 1.

Experiment XII. Infected four plants on 11th September, 1918, as follows :—.

(1) Two stems infected on tangential wounds and infections covered with cloth. Both these plants died—one on 19th September, 1918, and the other on 25th September, 1918.

(2) One stem infected on the stem surface and the infected section enclosed in a lamp chimney. This plant died on 25th September, 1918.

(3) One stem infected on a lateral shoot and enclosed in a glass lamp chimney. This infection took but did not ring the stem ; the plant remained healthy.

Experiment XIII. Infected five plants at the base of lateral shoots, and covered infections with cloth on 20th September, 1918. Four infections took—one plant was dead on 28th September, 1918, and three other plants died between 18th October, 1918, and 28th October, 1918. In this experiment out of five infections only one resulted in rapid death of the host. This result should be compared with the weather at the time of the infections (Pl. VIII) ; the influence of humidity and temperature upon the success or failure of inoculations is considered below with reference to some of the inoculations during 1919.

The following experiments were carried out in 1919.

Experiment XIV. In this experiment the inoculations were all done upon plants in pot culture. In each case the infection was carried out by placing a small piece of an actively growing agar culture of *D. Corchori* on the living stem and jacketing this section of the stem with a glass lamp chimney. The plants were grown from seed sown on 5th March, 1919.

(*a*) Two plants of green *C. capsularis,* two plants of red *C. capsularis* and two of red *C. olitorius* were infected on 27th June, 1919, at 10 a.m. The infections took upon the " kakya bombai ," producing a typical brown stain after 48 hours and ringing the stems by 10th July, 1919. Neither the red *capsularis* nor the *olitorius* was injured.

(*b*) Two plants of red *C. capsularis* and two of red *C. olitorius* were infected on 12th July, 1919, at 10 a.m. The infections upon red *capsularis* produced a brown stain on the stem in 48 hours ; the progress of the inoculations was exactly the same as on green *capsularis.* No result was obtained on red *C. olitorius.*

(*c*) Two plants of green *C. capsularis,* two of red *C. capsularis* and two of red *C. olitorius* were infected on 15th July, 1919, at 10 a.m. In each case one plant was infected upon the uninjured stem surface and the other in the axil of a small lateral shoot. All infections upon green and red *capsularis* took at once and one plant of each variety was dead by 22nd July (Pl. VI, fig. 1). In the case of the infections upon *C. olitorius* that in the axil of a lateral shoot set up a typical rot but did not succeed in ringing the stem and killing the plant.

Under the conditions of this experiment, therefore, the red *C. olitorius* seemed less easy to infect than either green or red *C. capsularis.*

Experiment XV. In this experiment the plants inoculated were growing in the field from seed sown on 5th March ; the infections were carried out upon the naked stem surface and were not jacketed in any way.

(*a*) Three plants of green *C. capsularis* were infected at 10 a.m. on 15th July in the axils of lateral shoots ; two others were infected in a similar situation after making a small tangential cut on the stem surface and one was infected in a small cut at the base of the stem. All the wound infections and one of the infections upon the uninjured stem took and produced a brown rot at the seat of infection within 24 hours. These plants all died from 7–14 days after infection (Pl. V, fig. 2). In the remaining two infections on uninjured stems the inoculum was lost, probably washed away by rain, in the 24 hours succeeding the inoculation.

(*b*) Six plants of red *C. capsularis* and six plants of red *C. olitorius* were infected on 7th August at 11 a.m. ; three plants of each variety were wounded. All wound infections took, with the usual symptoms of "black band," but in the case of the infections upon uninjured stems the inoculum in each case dried up and failed to infect the stem. The three wounded plants of red *capsularis* and one plant of red *olitorius* died 12 days after inoculation. In the remaining two wound infections on red *olitorius* the infection produced a black stain running up and down the stem, but did not succeed in ringing and killing the plant.

(*c*) Three plants of red *C. capsularis* and three plants of red *C. olitorius* were infected on the uninjured stem surface on 13th August at 10 a.m. The stem, at the seat of infection, was lightly covered with a small piece of cloth tied above and below the inoculum. Two of the infections upon red *capsularis* and one upon red *olitorius* succeeded in producing the typical discoloration on the stem but the plants were not ringed and did not succumb to the disease.

In this experiment, therefore, infections in the field were much less successful upon red *C. capsularis* and red *C. olitorius* than upon green *C. capsularis*. Under the conditions prevailing at the time of the inoculations the two red-stemmed varieties seemed less susceptible than the green-stemmed.

Experiment XVI. All the infections in this experiment were carried out on uninjured stems of green *C. capsularis* in the field ; each infection was covered with a small strip of thin white cloth. Controls with sterile agar were set up in each case.

(*a*) On 23rd August at 11 a.m. 22 plants were infected. In only five cases were there any signs of the infection taking and only one plant died.

(*b*) On 28th August at 6 p.m. 12 plants were infected. All these infections took and 8 plants died. The first plant wilted on 4th September and 8 plants were dead by 26th September, when the experiment was closed.

(*c*) On 14th September at 11 a.m. 12 plants were infected. Nine plants were killed by the fungus, during the next three or four weeks.

(*d*) On 18th September at 4-30 p.m. 11 plants were infected. Six plants were killed by the fungus.

In this experiment, therefore, there were marked differences in the results with a series of identical infections. The controls remained healthy throughout.

Experiment XVII. On 14th September at 11 a.m. twelve plants of red-stemmed *C. olitorius* were infected. The infections were carried out upon the uninjured stem and were covered with small strips of cloth as in the previous experiment. Ten infections took, producing the typical "black band" on the stem. The experiment was closed before the plants were killed by the fungus.

Experiment XVIII. All infections in this experiment were carried out on late sown plants of green *capsularis*; the plants were grown in pot cultures from seed sown on 20th June.

(*a*) Three plants, each about 12″ high, were infected on 23rd July at 10 a.m. All infections were jacketed with lamp chimneys, and three controls, consisting of plants with a minute piece of sterile agar on the stem, were also jacketed. On 27th July one of the infected plants was dead, the remaining plants, both inoculated and controls, remained healthy.

(*b*) This experiment was a repetition of the last; the infections were made on 7 h August at 11 a.m. Of three plants infected one was killed by 4th August —the remaining infections did not take.

(*c*) On 25th July at 10 a.m. twelve plants were infected; these plants were *not* jacketed with lamp chimneys and the pots were standing in the open air on a verandah. One plant was killed by the fungus, the remaining 11 plants were not affected, the inoculum drying up.

(*d*) On 10th August at 10 a.m. these eleven plants were again infected. Six of the infected plants were killed by the 14th August and three more died by 23rd August (Pl. VI, fig. 2).

Factors in the Incidence of the Disease.

Evidence has clearly shown that *D. Corchori* has been widely diffused in Bihar, Bengal and Assam for many years past; therefore in the season 1917, when the disease was bad, there must have been some factors favourable to the appearance of "black band," which were not acting in 1918 or 1919, when the incidence of the disease was much less severe.

The analysis of the factors which produce any epidemic is a task of great difficulty, since of the numerous causes to be evaluated each has to be considered in relation to both parasite and host. Thus a disease may increase in virulence owing to some change in the host which renders it a more favourable medium for the growth of the parasite or to a condition directly favouring the development of the parasite ; or both these factors may operate at once.

In dealing with a fungal disease one of the first factors to be considered is the variation between the climates of different years. It has already been mentioned that the disease develops most severely upon the mature plant, the crucial months being usually August and September. The principal features of the climate in these months in 1917, 1918, and 1919 are shown on Plates VII, VIII, and IX from which it appears that these months in 1917 in Bihar were generally more humid and cooler than the corresponding periods in 1918 and 1919. These two factors of temperature and humidity probably affected both parasite and host ; the weather of 1917 being in respect of its higher humidity more favourable to the fungus and delaying the ripening of the crop, thus giving the parasite more time to act. Such a correlation between humidity and disease is by no means uncommon. Thus the determining factor in the incidence of wheat rust in certain parts of India appears to be the atmospheric humidity during the early months of the year.[1]

The influence of climate on the incidence of " black band " disease was further emphasized by a study of the weather conditions during the inoculation experiments of 1919. In certain cases (Experiments XV*a* and XVI*b*, *c*, *d*) the percentage of successful infections was high, while in others (Experiment XVI*a*) the inoculations were a failure. It is suggested, by a comparison of the dates on which infections were made with the conditions of temperature and humidity prevailing at the time (Pl. IX), that the successful inoculations were those which coincided with a relatively high humidity, and that inoculations which failed were those carried out during a period of lower humidity and higher temperature. All these infections were carried out on " kakya bombai " in the field, and for a complete investigation of the influence of climate on infection a detailed record of humidity and temperature actually recorded in the jute field during a series of infections is required. It is not possible to give these data at present but Plates X and XI show a complete record for these conditions during Experiments XVI*a*, *b* and XVIII*c*, *d*, obtained from a hygrometer working in a laboratory within a short distance of the site of the experiments. A more numerous series of observations is needed to establish the relations between humidity and temperature, and the success or failure of inoculations. It may be recalled, however, that in certain cases the limits of humidity within which infections can occur have been proved to be relatively narrow. Thus it is stated[2] that infections of wheat with *Puccinia graminis tritici* do not succeed below a humidity of 95 per cent. at a temperature of 68°F., and that the range of infection of bean (*Phaseolus vulgaris*) with *Colletotrichum Lindemuthianum* (Sacc. et Magn.) Biv. & Cav. lies between 92 per cent. and 100 per cent. at a temperature of 68°F. In the case of buck wheat (*Fagopyrum esculentum* Mœnch.) with *Ascochyta Fagopyrum* the range of infection at 77°F. lies between 90 per cent. and 100 per cent.

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[1] Butler, E. J. " Fungi and Disease in Plants." Thacker, Spink & Co., Calcutta, 1918. p. 110.

[2] Lauritzen, J. L. " Relations of Temperature and Humidity to Infection by certain Fungi." *Phytopathology*, Vol. IX, Jan., 1919.

The fact that late sown jute, and generally the smaller stems, escape the disease has been frequently mentioned and suggests a method of raising a clean seed crop. Of the cause of this relative immunity in late sown jute little can be said at present ; that the immunity of late sown jute is not absolute is shown by the successful infections in Experiment XVIII. It is noteworthy that when from some local richness of soil late sown plants attain a large size they are frequently attacked by the disease. This suggests that the relative immunity of smaller stems may perhaps be due to some anatomical difference in the external layers which renders the smaller stems less liable to penetration by the germ tube of the fungus, or more probably that the development of a large stem is connected with some physiological condition which renders it a more favourable medium for the parasite. Other cases in which the host plant is more susceptible to the attack of a parasite when in the mature condition are not unknown. The susceptibility of *shaftal* (*Trifolium resupinatum*) to the attack of *Polythrincium Trifolii* in the Peshawar District being a case within the writer's experience. Chemical investigations are in progress on the composition of jute stems from late and early sown crops but are not, at present, sufficiently advanced to admit of any discussion. There is a suggestion, in the results obtained up to date, that the stems of late sown jute are richer in soda (Na_2O) and sulphuric acid (SO_4) than those of the early sown crop.

Field Experiments.

During the process of threshing out jute seed it was obvious that a large number of spores of *D. Corchori* would become mixed with the seed and might serve to disseminate the disease in the next season's crop. Microscopic examination of samples of jute seed from a badly diseased crop showed the presence of *Diplodia* spores among the seed ; the fact, however, that *D. Corchori* was already present in the jute-growing districts suggested that the presence of spores mingled with the seed would not prove a very potent factor in increasing the amount of disease. As, however, the Bihar seed crop was to be distributed throughout the jute-growing districts of Bengal in small packets, it was considered advisable to disinfect the seed, pending the results of experiments designed to show whether seed disinfection had any influence in lessening the incidence of the parasite. Experiments showed that jute seed could be steeped for 10 minutes in a 2 per cent. solution of copper sulphate and thoroughly dried without injury to germination, and that this treatment would inhibit the germination of the spores of *D. Corchori*. In 1918, and in 1919, therefore, the whole of the jute seed crop of Bihar was disinfected in this manner before despatch to Bengal, and in these years the experiments detailed below were carried out in Pusa and the vicinity to test whether this treatment had any effect on the incidence of the disease.

In 1918 the following field experiments were made :—

Plots A and B. Two plots, each about $\frac{1}{20}$th of an acre, were sown on 5th March with jute seed ("kakya bombai") obtained from the diseased Pusa crop of 1917. This seed had not been treated by steeping in copper sulphate solution, but the land had not been under jute for over 20 years and no other jute was in the vicinity. One plot (A) was thinned out to a distance of 18″ between plants, the other plot (B) was not thinned. Both plots gave a good crop. In the crop which had been thinned out the plants reached a height of 14 feet and a thickness of 1–1½ inches, but in the crop which was not thinned the plants only reached a height of 8 feet and the stems were much thinner. The plots were kept under observation throughout the season, and were cut and harvested on 5th November; the *Diplodia* disease was practically absent, only some half dozen infected plants occurring in each plot.

Plots C and D. These were a repetition of the two previous plots, Plot C being thinned out, and gave the same result.

From these experiments in which disease-free soil was sown with untreated seed, and in which the disease failed to appear to any appreciable extent, it may be inferred that the spread of the disease through spores mingled with the seed is not very serious.

Plots E and F. Two plots, each about ¼th acre, were sown with treated jute seed ("kakya bombai") on 1st March. The plots were situated in a portion of the field in which jute had been grown during the previous season and where the disease had been particularly bad. Unfortunately owing to deficiency of moisture during March and April, the seed did not germinate and the plots had to be resown at the end of April. Germination when it did take place was late and the crop in size and appearance resembled the ordinary late sown crop. Owing also to irregularity in germination in both plots the plants were fairly widely separated and the original intention of thinning out one plot was useless. Both these plots showed more *Diplodia* disease than the previous plots. Thus Plot E had 67 plants infected with *Diplodia* and Plot F had 54 plants infected with *Diplodia*.

In this experiment, therefore, a crop, which was virtually a late sown crop grown from treated seed, developed the disease when grown in land which had carried diseased jute during the previous season.

Plot G. This plot, about ¼th acre, was situated outside Pusa in land which had not been under jute for many years and which had no other jute near it. The crop was grown from treated seed ("kakya bombai") sown on 11th March. The plot was about ¼ acre in size and germination was at first uneven owing to deficiency of moisture. The crop did not reach a good height but was fairly thick in the stem; one end suffered considerably from flooding. There were about 60 cases of *Diplodia* in this crop.

In 1919 a further series of field experiments was made.

Plots A and C. These plots were sown with seed of "kakya bombai" about 5th March, the former with treated and the latter with untreated seed. *D. Corchori* was practically absent in both these plots, only some 3 or 4 cases could be seen. A crop of *Corchorus olitorius* in Plot B and one of red-stemmed *C. capsularis* in Plot D also remained free from the disease.

Plots E and F. These two plots from last season's experiment were again sown with jute of the variety "kakya bombai," the seed used had been steeped in a solution of copper sulphate, and this land had been under jute since 1917. In 1919, therefore, germination was very scanty. Both plots were resown on 4th July, after the commencement of the rains, and gave a crop of typical late sown jute, short in height and thin in stem. In both plots the number of stems infected with *D. Corchori* was negligible, only about 12 cases could be found when the crop was cut early in November. Thus in these plots the disease was less in 1919 than in the previous season.

Plots H and K. About ⅓rd of each plot was sown on 5th March with a red-stemmed variety of *Corchorus capsularis* and the remainder with "kakya bombai." These plots were situated in the land which had carried the diseased jute in 1918. Both the varieties of seed sown had been steeped in 2 per cent. copper sulphate. Plot H carried a very scanty crop and had 31 cases of *D. Corchori* among the "kakya bombai" stems and only 6 cases in the red-stemmed variety. In plot K the crop was much thicker, both germination and growth having been better than in plot H. In Plot K there were 190 cases of *D. Corchori* among the "kakya bombai" stems and 34 cases in the red-stemmed variety.

In both these plots, allowing for the larger proportion sown with "kakya bombai," the red-stemmed variety suffered less than the green-stemmed. This result agrees with the result from infections upon red and green-stemmed varieties of jute (*see* Exp. XV), but at the same time it must not be lost sight of that the disease can infect red-stemmed jute in the field as is shown by the record at Dacca in 1919.

Plots M and N. These plots, each about ¼th acre, were selected in good land which had never carried jute before. Plot M was sown on 5th March with seed of "kakya bombai" which had been treated by steeping in copper sulphate solution, and Plot N was sown on the same date with seed which had not been so treated. Both plots gave an excellent crop of jute 9–11 feet in height. In both plots nearly the same number of stems were diseased owing to *D. Corchori*—76 stems in Plot M and 56 in Plot N.

As a result of these field experiments, particularly from a consideration of Plots M and N in 1919, it cannot be said that seed steeping in a solution of copper sulphate has any influence on the severity of the disease, and, therefore, as mentioned above, the dissemination of the disease cannot take place to any appreciable extent through spores of *D. Corchori* mingled with the jute seed. The percentage of disease was also not to any extent greater in those plots which had been under jute for two or more successive seasons.

Conclusions.

The present investigation has shown that—

(1) *Diplodia Corchori* Syd. is a parasite of the jute plant.

(2) The disease occurs after flowering and threatens the seed crop.

(3) The fungus is widely distributed in jute-growing districts.

(4) The intensity of the disease varies greatly from one season to another.

(5) The disease is most severe on large, well-grown stems, and infection takes place more readily upon green-stemmed than upon red-stemmed varieties.

Further research is required to show the precise mode of infection, the limits of temperature and humidity under which infection will take place, and the qualities which render the late sown crop resistant to the disease. Direct treatment against a disease such as this is scarcely possible in the case of the jute crop, and we must look to an increased knowledge of the factors which condition success in the life of the parasite, and to the possibility of modifying these factors by alterations in the culture of the host, for the effective control of this disease.

Any disease which threatens the jute plant might, in view of the importance of this crop in the economic life of Bengal, become a factor of grave agricultural importance. It is a matter of congratulation that the crop is generally free from fungal disease and that the parasite, which forms the subject of the present paper, is not a source of danger to the fibre crop. Another stem rot of the jute plant is caused by a fungus, which has been identified[1] in Japan as *Macrophoma Corchori*[2] Saw. This fungus occurs in India,[3] where its depredations are not confined to the jute crop, and will form matter for a later communication.

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[1] Kaneyoshi Sawada. "Preliminary Report of a new Stem Rot Disease of Jute caused by *Macrophoma Corchori* Saw. sp. nov." *Bull.* 107 *Agric. Expt. Sta. Formosa*, 1916.

[2] *Mycologia*, Vol. XI, No. 2, March, 1919, p. 82.

[3] *Scientific Reports of the Agricultural Research Institute, Pusa*, 1918-19, p. 71.

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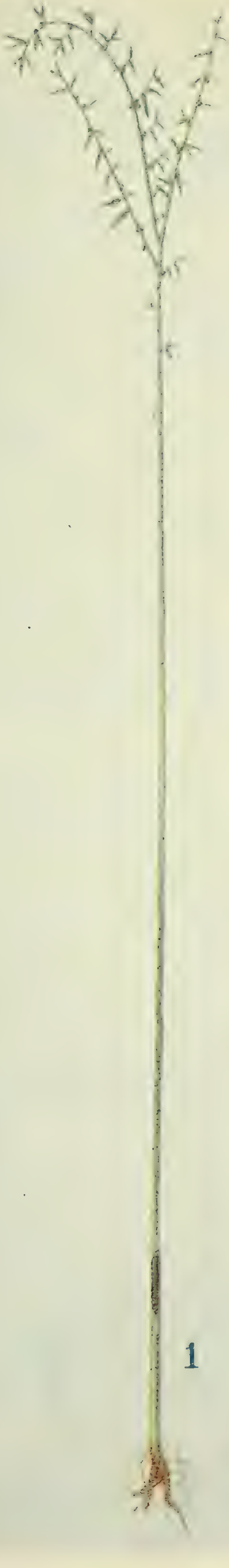
PLATES X, XI. Curves of humidity and temperature during periods of Experiments XVI*a* & *b* and XVIII *c* & *d*.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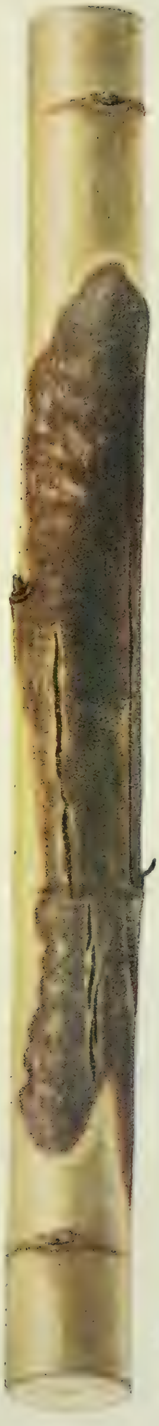
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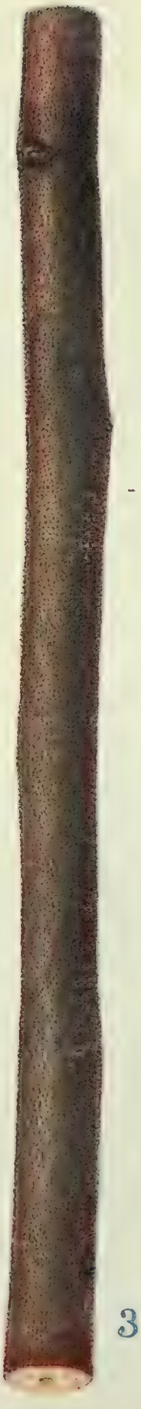
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PLATE II.

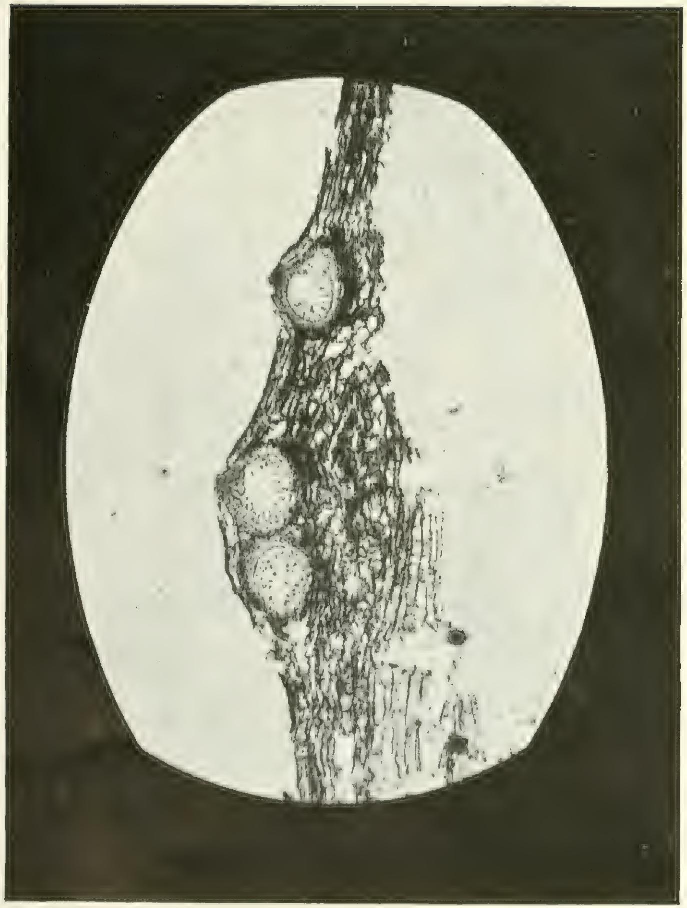


Fig. 1. Microphotograph of a section of the cortex a diseased stem showing three pycnidia of *D. Corchori* (x90).

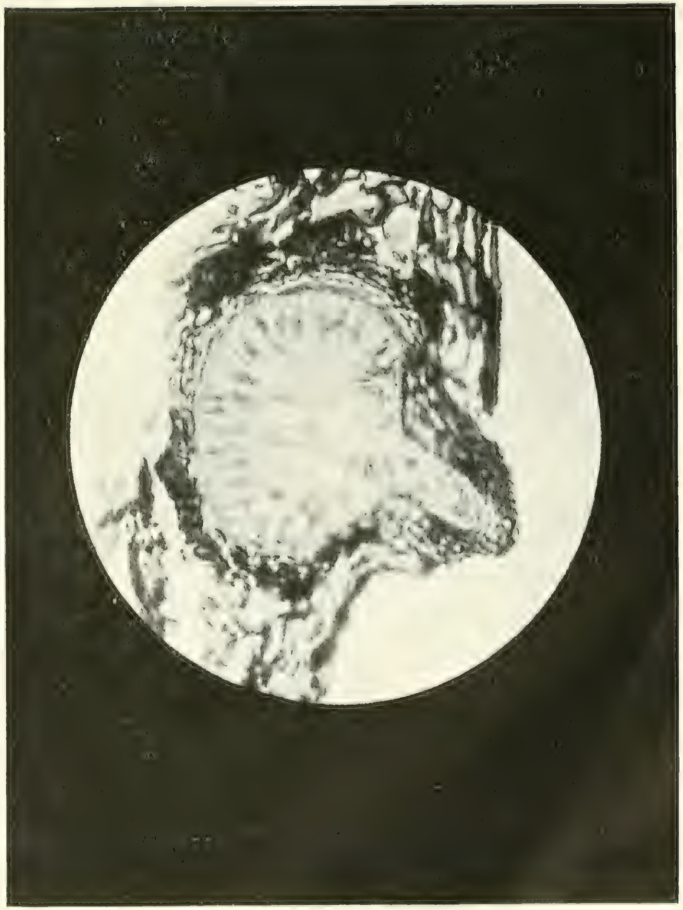


Fig. 2. Pycnidium of *D. Corchori* (x500).

PLATE III

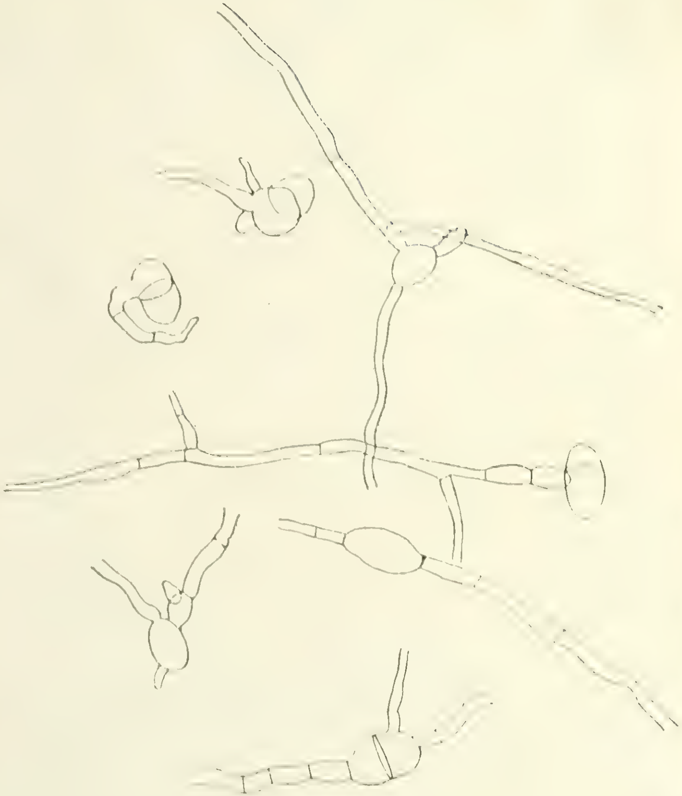


Fig. 1. Germinating spores of *D. Corchori* (x500).

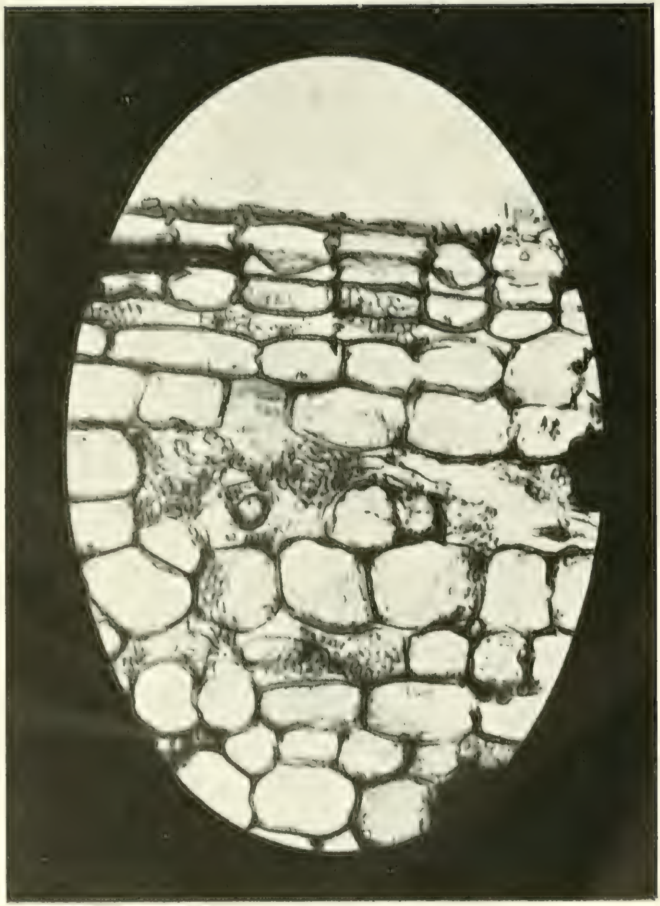


Fig. 2. Section of a cortex showing a hypha of *D. Corchori* setting up disintegration in the cells (x600)

PLATE IV

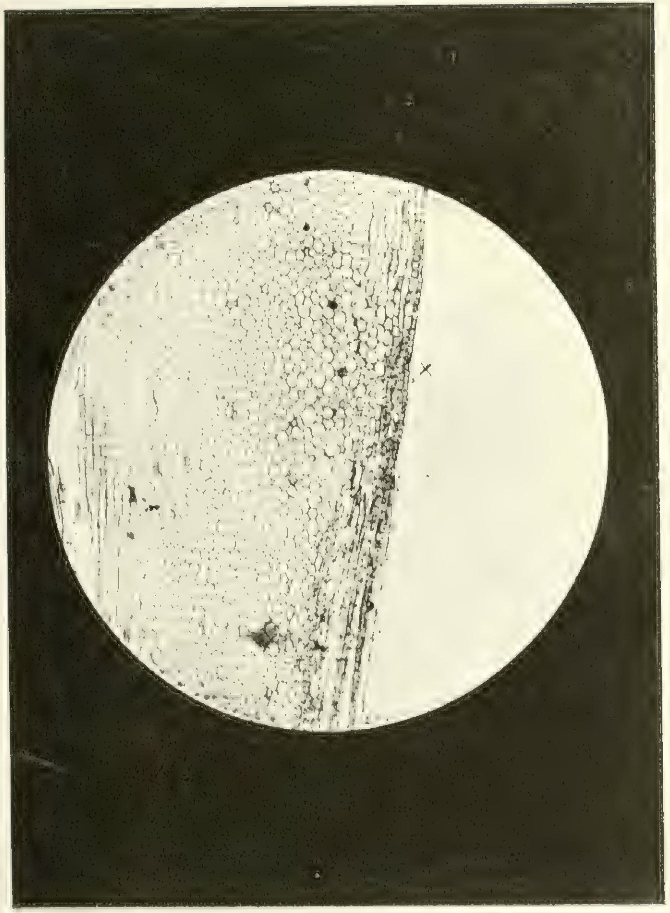


Fig. 1. Section of the cortex showing an early stage in an infection. The diseased tissue is visible between the marks xx.

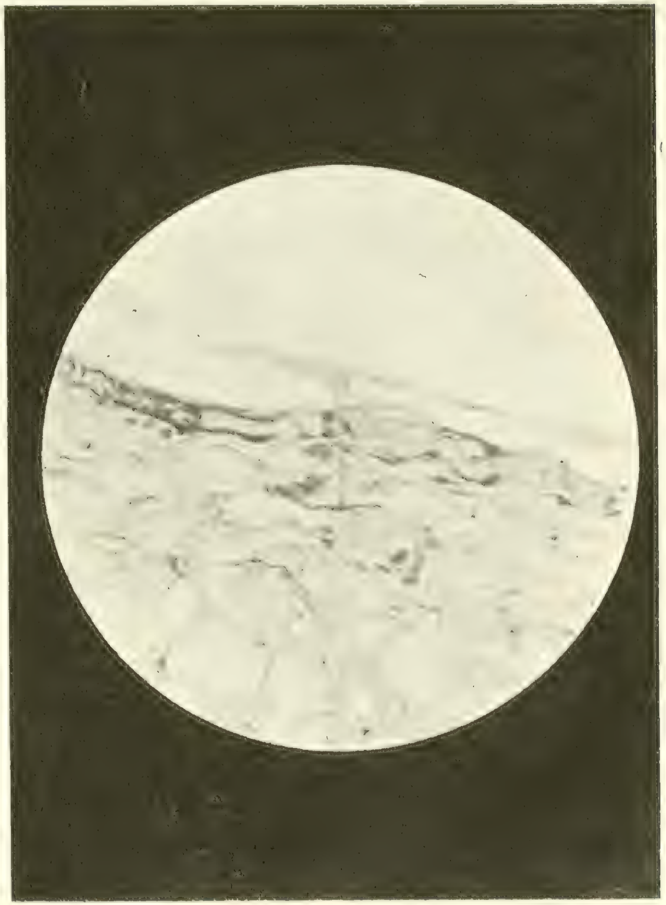


Fig. 2. A section of epidermis and cortex showing a hypha penetrating an epidermal cell (x600).

PLATE V.

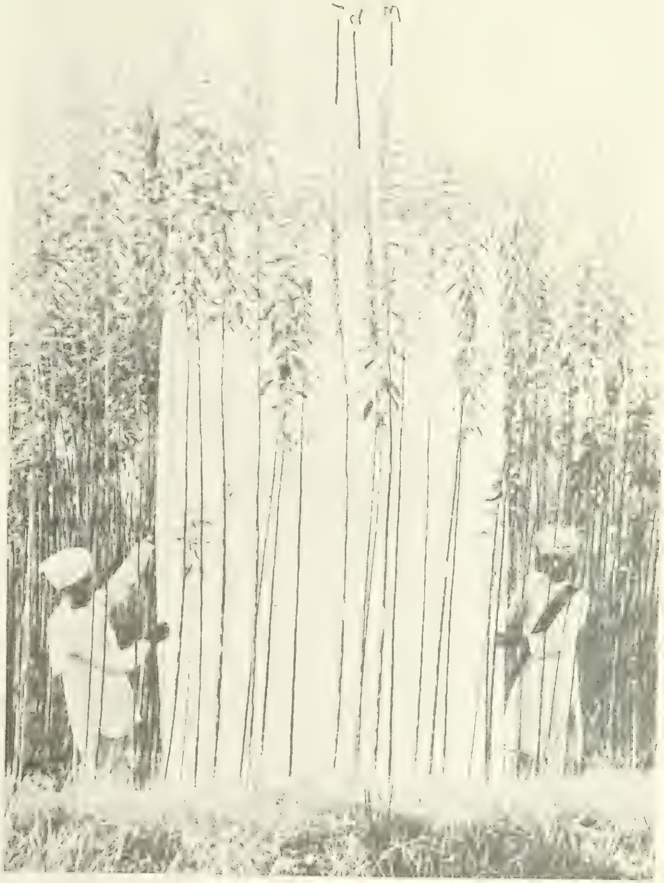


Fig. 1. Three jute plants dead as the result of inoculation.

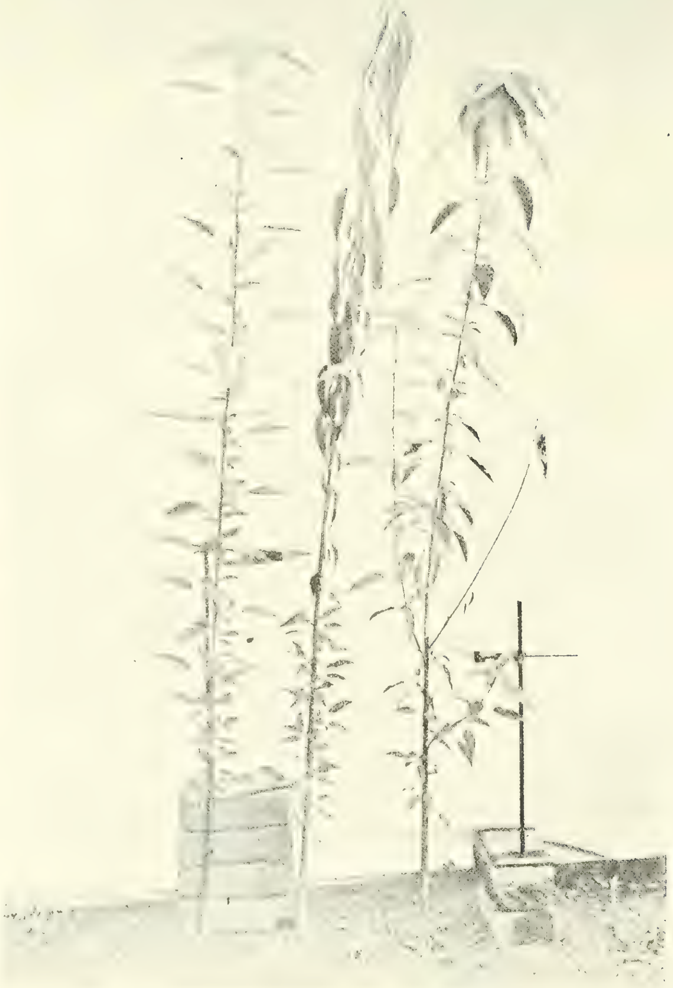


Fig. 2. Three plants of "kakya bombai." Left hand plant healthy; centre plant wilting as the result of inoculation; right hand plant inoculated at the base of lateral shoot.

PLATE VI.

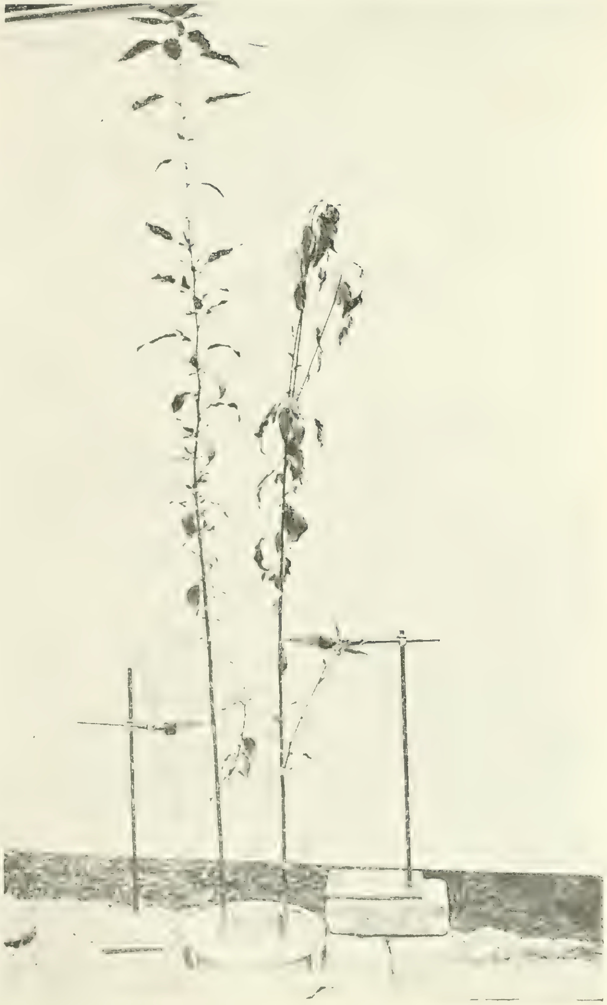


Fig. 1. Infections upon two plants of red-stemmed variety. Righthand plant wilting.

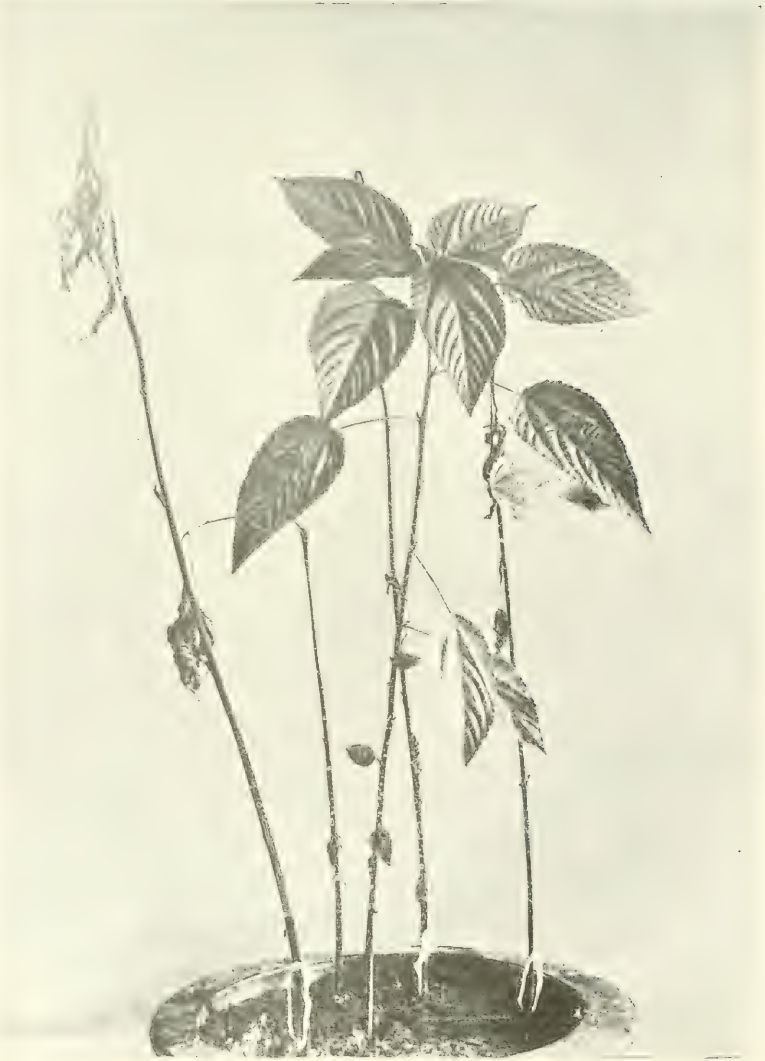
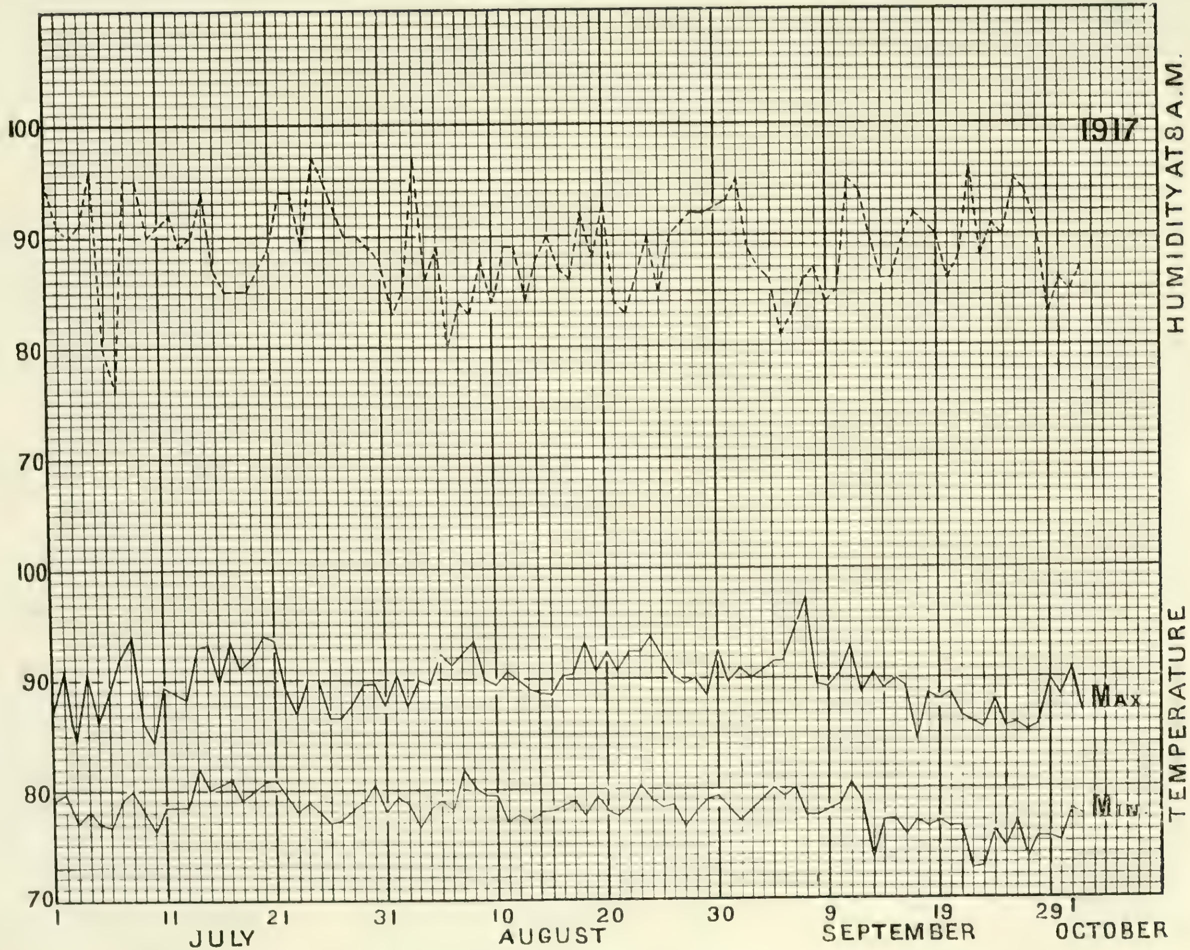
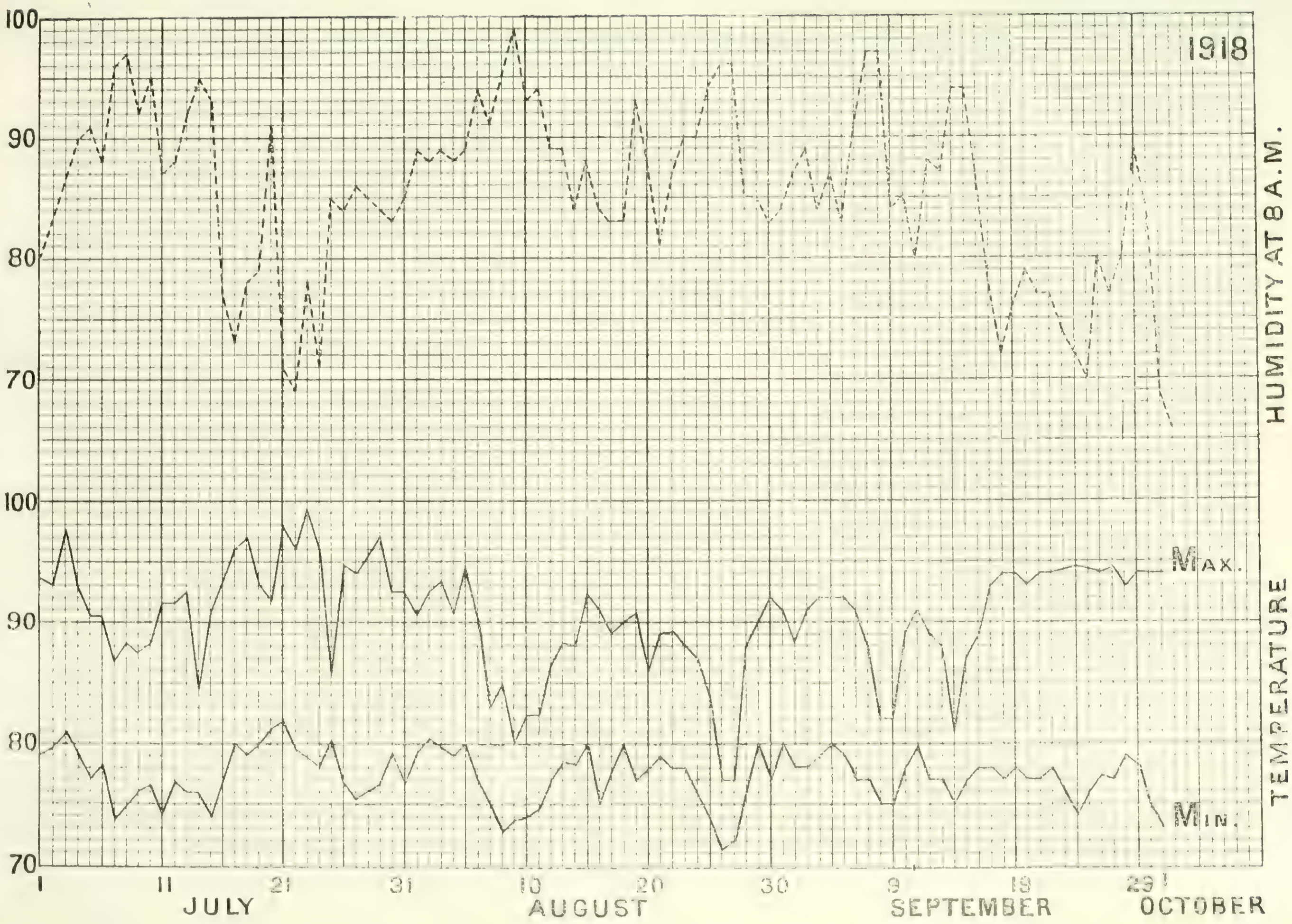


Fig. 2. Five plants of late sown jute. Four infected with *D. Corchori* are dead. Fifth, not infected, is healthy.

PLATE VII.

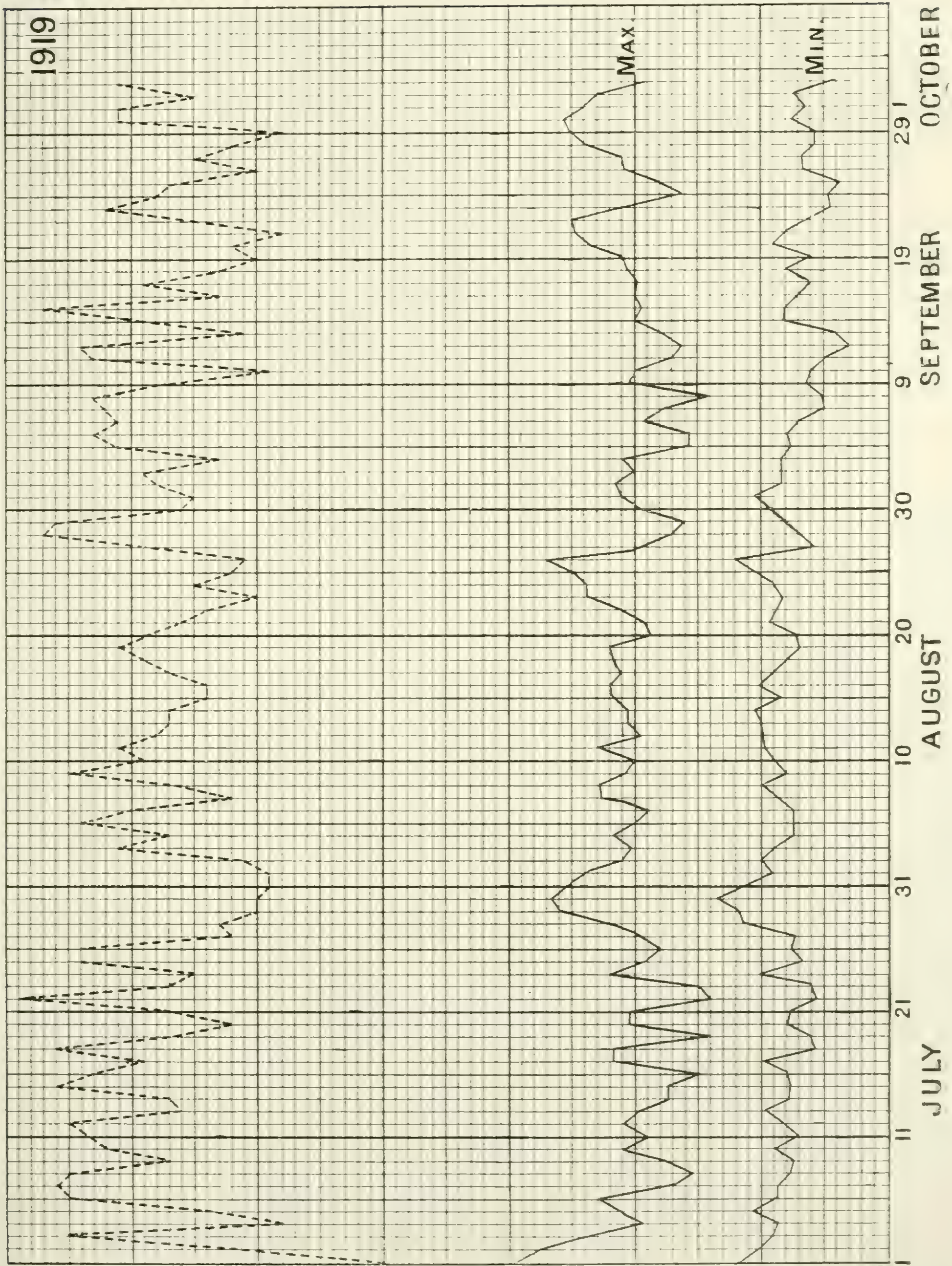


Temperature and 8 a. m. humidity curves of July, August, and September 1917.



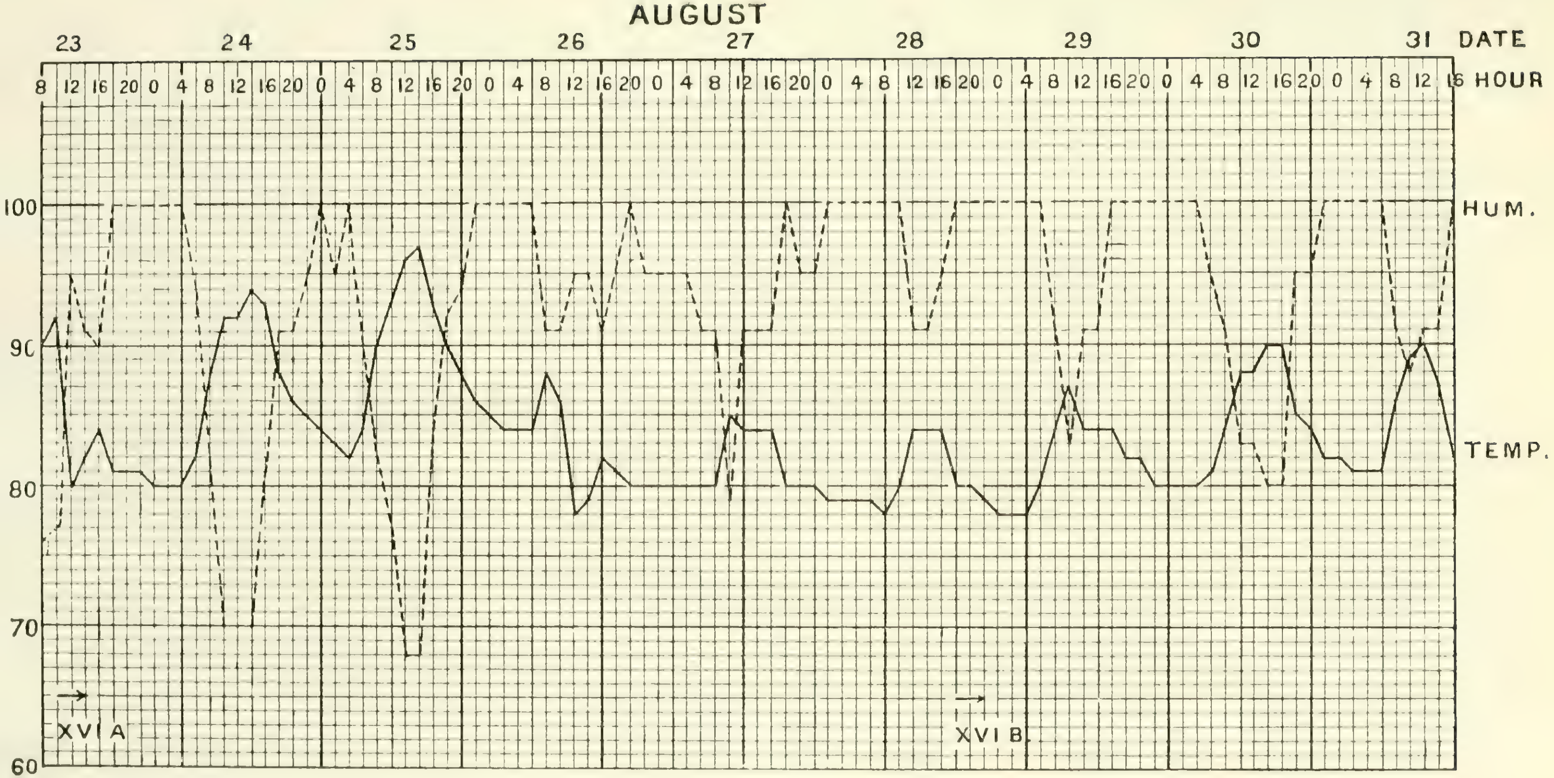
Temperature and 8 a. m. humidity curves of July, August, and September 1918.

PLATE IX.

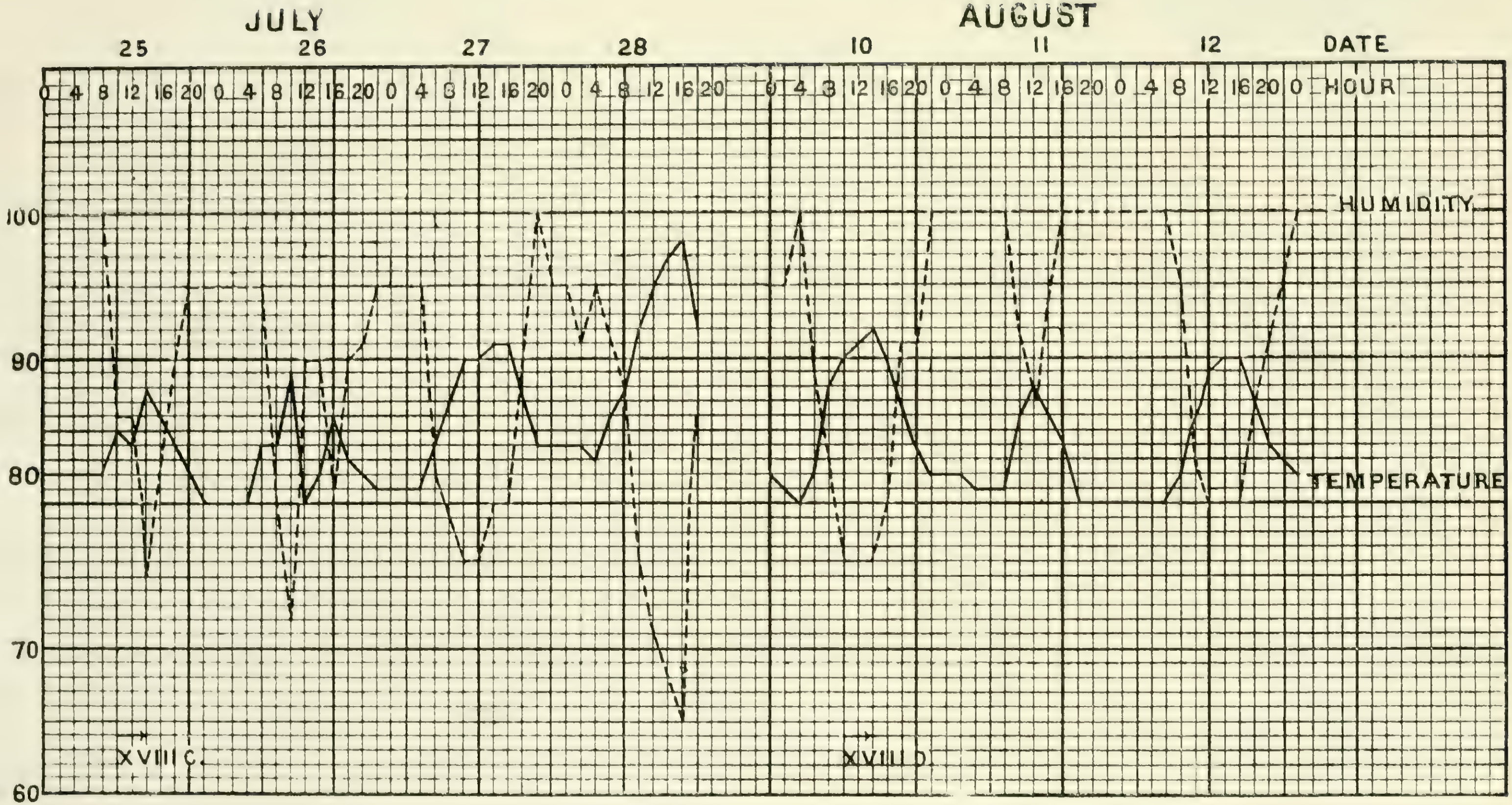


Temperature and 8 a. m humidity curves of July, August, and September 1919.

PLATE X.



Curves of humidity and temperature during periods of Experiments XVI *a* and *b*.



Curves of humidity and temperature during periods of Experiments XVIII, *c* and *d*.

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January 1921. Botanical Series. Vol. XI, No. 3.

Memoirs of the Department of Agriculture in India

MORPHOLOGY AND PARASITISM OF *ACROTHECIUM PENNISETI* N. SP.

(A NEW DISEASE OF *PENNISETUM TYPHOIDEUM*)

BY

MANORANJAN MITRA, M.Sc.

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AGRICULTURAL RESEARCH INSTITUTE, PUSA

PRINTED AND PUBLISHED FOR
THE IMPERIAL DEPARTMENT OF AGRICULTURE IN INDIA

BY
THACKER, SPINK & CO., CALCUTTA
W. THACKER & CO., 2, CREED LANE, LONDON

Price, Re. 1-4 or 2s.

EDITED BY

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January 1921 BOTANICAL SERIES VOL. XI, NO. 3

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[Received for publication on 2nd June, 1920.]

1. Introduction.

Pennisetum typhoideum Rich. (vern. Bajra) is a tall, erect grass of African origin. The total area under it in India is about 13,320,250 acres, yielding 2,197,425 tons of grain. In the order of importance it takes the fourth position among the cereals, following rice, wheat and *Sorghum*.[1] It is very commonly cultivated in North-West, Central and Southern India, as a cereal food and also for fodder. In the Bombay Presidency the area occupied by it is considerably over 4 million acres, and in many parts it forms the staple food of the people. It is generally sown in June, and the crop ripens in September. In Sind and Rajputana, it is the most important *kharif* crop. In Madras and the Punjab, it is grown to a very great extent and is used both as a staple food and fodder.

The number of fungus diseases hitherto reported as attacking this crop in India is not large: *Sclerospora graminicola* (Sacc.) Schroet., *Puccinia Penniseti* Zimm., and *Tolyposporium Penicillariæ* Bref. being the chief.[2]

A parasitic species of *Acrothecium* is very common on Bajra at Pusa, which occurs every year and seems to cause considerable damage. It has never been recorded before, though its presence is noticed on diseased ears occasionally sent to Pusa from outside. Thus the fungus was found on ears sent to the Imperial Mycologist by the Superintendent, Government Farm, Alibag (Bombay), in 1919.*

The genus *Acrothecium* is a Deuteromycete belonging to the group Dematiaceæ, Phragmosporæ. The chief characteristic of this genus is that the conidiophore is simple, erect, and of dark colour, and bears a group of two to many-celled, dark-coloured conidia at its tip.

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[1] *Agri. Statistics of India*, 1918–19, Vol. I.

[2] Butler, E. J. "Fungi and Disease in Plants," 1918, pp. 218—226.

* Since this paper was submitted for publication, the writer has found it to be very common at Cawnpore, Hansi, Amritsar, Gurdaspur, Lahore and Lyallpur.

There are several species of *Acrothecium* recently found at Pusa on various hosts, *viz.*, Jowar (*Sorghum vulgare*), maize (*Zea Mays*), rice (*Oryza sativa*), and wild grasses such as *Andropogon* and *Panicum*, and all these have been brought into culture and are under investigation.

2. The disease : Its description.

At Pusa, the organism appears on leaves, leaf-sheaths, and on ears. Since it is most common on the leaves, the disease may be called "leaf spot or leaf blight of *bajra*."

(*a*) *Appearance on the leaves.* In the beginning the infected leaves show small yellowish-brown spots which gradually spread more in the longitudinal direction and become oval or oblong. The centre of the spot soon changes to a dirty brown colour, around which the margin remains yellow. Sometimes the spots coalesce and form irregular patches. They are most frequent towards the edge of the leaf, and in cases where they are situated near each other they soon run together, unite and form a big spot, killing the tissue along the margin of the leaf and gradually extending towards the midrib. Frequently both margins are infected and the whole leaf is gradually killed. The spots occur on the midrib also, especially on those of young leaves and, in severe cases, even on the leaf-sheaths. Very often the infection begins from the tip of drooping leaves and goes on increasing and extending towards the base, either along the margin or along the midrib or both together. The infected portion of the leaf becomes brittle with age. The disease begins from the lower leaves, then gradually spreads and attacks the upper leaves. In the lower leaves the infection begins from the tip of the drooping leaves which either touch the soil or are very near to it.

From the observation made at Pusa in 1919, it has been found that the disease makes its appearance in June on the lower half-dead leaves of young plants, but is associated with many other saprophytic organisms. With the increase of rainfall in July, it becomes more and more prominent and is found on the lower leaves of a large number of plants. In August and September it is also found on the upper leaves. Towards the middle of September (in 1919), almost all *bajra* plants were found to be more or less affected. The spread of the disease is facilitated by the moisture which the tip and margin of the leaves retain during the monsoon on account of their being a little up-turned (Plate I, figs. 1 and 2).

(*b*) *Appearance on the ears.* Not only leaves and leaf-sheaths but the ears also are attacked by this fungus (Plate I, fig. 3). The glumes and palæ of the flowers show the presence of this fungus. The infection begins from the tip of the floret and gradually the whole spikelet gets infected. From the first scattered infected spikelets the attack spreads to those in the neighbourhood, and in a badly infected ear very few normal grains are formed. When once the ear is weakened by the disease, other fungi also make their appearance. An infected flower shows a tuft of black mould at its tip, and inside mycelium is found in the ovary and anthers. Plate I, fig. 3, shows an ear which was inoculated in a few places.

3. THE ECONOMIC IMPORTANCE.

The organism appears to cause considerable damage to the leaves and ears of *bajra* and affects the growth and production of sound and healthy grains. It hinders the assimilation of carbon dioxide by the leaves and thus the plant is starved to some extent. Further information as to the amount of damage it does to the crop in years when the attack is severe is required.

4. THE MORPHOLOGY OF THE FUNGUS ON THE HOST.

Mycelium. The mycelium consists of septate hyaline hyphæ which ramify in the tissues of the host. It is olive brown in colour where conidiophores are given off. It is both intra and inter-cellular, and is found in all parts of the diseased tissues, even in the cells of the endodermis, sclerenchyma and vessels. Haustoria are not present.

Conidiophores (Plate II, figs. 1 and 2) are present in greater number in the central dead portion of the spot and they gradually get lesser and lesser towards the margin. They come out from the stomata of the leaf blade and midrib. They are amphigenous, solitary, fasciculate, rigid, erect, straight or slightly nodulose or bent ; simple and 3—5 septate. Rarely they are forked near the tip (Plate II, fig. 2*a*). In colour they are olive brown to dirty brown with paler tips which are either swollen or flexuous. The base sometimes is also swollen. They measure 68·4—154 μ long and 5·8—8·7 μ broad.

Conidia (Plate II, fig. 3) are clavate, pear-shaped, or elongated, straight or slightly bent, thick-walled, 2-3 septate, light olive-brown to dirty brown in colour, end cells lightly coloured and middle one broader and darker. They are constricted at the septa and are borne at the tip of the conidiophore in groups of 2—5. Very rarely conidia on the sides of the conidiophore below the tip are noticed. They measure 25—41·8μ × 12·5—20μ.

5. CULTURES.

Pure cultures were obtained several times from typical leaf spots by single spore isolations from poured plates. The spores germinate freely in glucose agar and can be picked up and transferred to culture tubes.

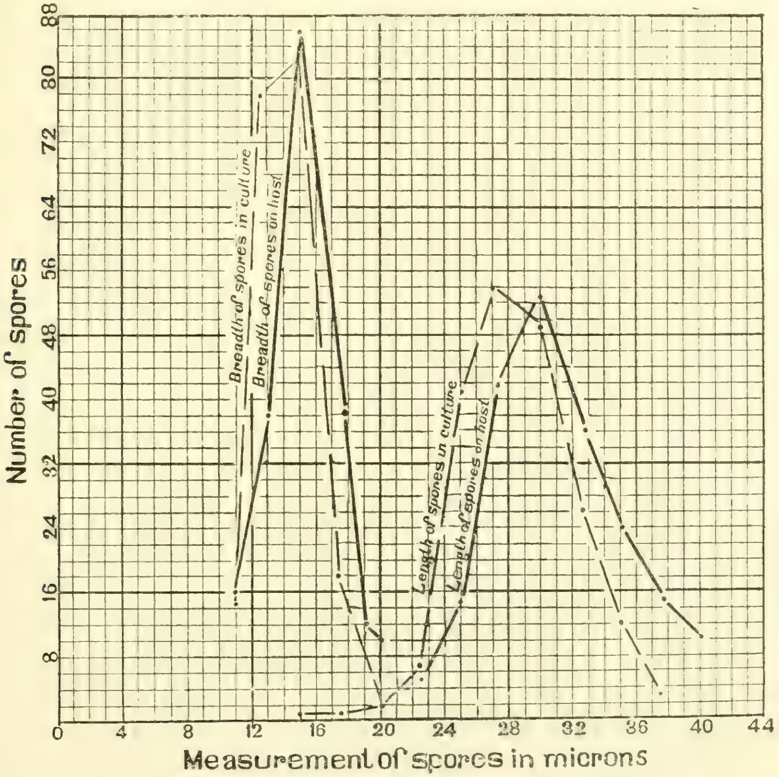
(*a*) *Germination of conidia and growth of fungus in distilled water.* The spores readily germinate in distilled water. Fresh spores begin to give out germ tubes after one or two hours from placing in water (Plate II, fig. 3*a*; and Plate III, figs. 6—10). Germ tubes protrude either from one end or from both. The tube is swollen at the base, hyaline and sparingly septate in the beginning. Sometimes two germ tubes come out from two points in one extremity (Plate II, fig. 6) or a single germ tube which at once bifurcates. The hyphæ elongate, branch and anastomose, and form a net-work of mycelium which only sometimes produces spores in water. These spores are smaller in size than those produced in culture tubes. In hanging drop cultures either a very few or none at all germinate. Probably this has something to do with the supply of oxygen. Frequently no spore formation takes place in closed culture tubes, but when a little of the culture is placed on a slide with a drop of distilled water and is incubated, a free production of conidiophores and conidia results. This is probably due to a combination of free supply of oxygen and moisture together with a lesser amount of food. Sometimes, instead of the formation of conidia the tip of the conidiophore grows out into a hypha (Plate II, fig. 7).

(*b*) *Morphology of the fungus in culture.* In ordinary nutrient glucose agar the fungus grows profusely. In the beginning the aerial mycelium is pale but it gradually changes to light pink and then to greyish brown. With the increased growth of the fungus the medium turns dark brown. The submerged and creeping hyphæ are hyaline to light greyish brown in colour. The mycelium is septate with cells up to 7·5 μ in diameter, and goes on branching and anastomosing and producing a large number of conidiophores at right angles to the main hyphæ or at their tips (Plate II, figs. 4—6).

The conidiophores are deeper in colour but in diameter generally they are of the same size as the sterile hyphæ. There is not much difference in the characters of the conidiophore as formed in culture from those already described on the host. They generally bear 2—5 conidia at their tips (Plate II, figs. 4—6) but sometimes only one and occasionally more than 5 are seen. In the beginning a small bud-like projection appears, this soon increases in size; septa develop and thus a conidium is formed. At first one appears, then another, and so on, till a group of 2—5 is formed.

Frequently, on some media, a second set of conidia is formed below the tip. on the sides of the conidiophore, and often the conidiophore, after producing a group of conidia at the tip, resumes its growth, and produces another group, while the first group either remains adherent or gradually gets detached. In the latter case the conidiophores are quite long, and are angularly bent and nodulose at the point where there has been a formation of conidia. This formation of secondary sets of conidia takes place in old cultures and, to a somewhat lesser extent, in cultures that are taken out of the tube and incubated for some days on slides. When the conidiophore is formed at the end of a hypha (Plate II, figs. 4, 6), it is distinguished from other hyphæ by its colour which turns distinctly deeper from a particular septum.

The characteristics of conidia have already been described, but those produced in culture are slightly smaller in size than those found in the field. The accompanying curve (Text-figure) is drawn to compare the length and breadth of conidia in nature and in artificial culture. The conidia generally are 2–3 septate, but in culture sometimes uniseptate ones are formed (Plate III, fig. 11)



The formation of chlamydospores takes place in most of the cultures. The cells of a hypha swell up singly or sometimes in a long line, become spherical or oval in shape, later on become thick-walled and, as the culture gets old, turn brown or greyish brown in colour. These chlamydospores either remain united in a chain or separate, and often germinate to give rise to new hyphæ (Plate III, figs. 1—3).

(*c*) *Growth of fungus on different culture media.* A comparative study of the growth of the fungus has been made on 20 different culture media. Two tubes of each medium were inoculated on the same day and all these tubes were kept at the room temperature which was between 20 and 23°C. Media of known reaction were employed and the reaction of each is indicated with the cultural description. All the media used were acid in reaction, ranging from + 2 to + 9 Fuller's scale. The composition of the media is given at the end in the Appendix (p. 72).

The fungus can grow well on most media tried, but does best on potato juice agar, wheat broth agar, nutrient glucose agar and French-bean agar. In all of these growth was profuse and the mycelium spread even on to the walls of the tubes. Conidia were formed in large number except on French-bean agar, on which only a few spores were observed. Of the above four media, potato juice agar and wheat broth agar were the best, both as regards the growth and production of spores. Besides these a fair growth was also found on the other meal agars described below. The growth was poor on glycerine agar, cellulose agar and on corn leaf juice agar. Details of the growth on all the media are given below.

1. *Potato juice agar* (+6 Fuller's scale). The growth is best on this medium. Woolly aerial mycelium fills three-quarters of the tube in a few days and spreads on the walls. The colour in the beginning is light grey, but later on it changes to dark grey. There is a slight tinge of pink present on the sides where the medium and the tube meet. In six days the growth is very profuse and the tube is quite full ; the mycelium becomes darker and the medium gradually turns yellowish in colour. The creeping hyphæ are subhyaline and in older cultures they become olive brown. They are up to 7·5μ in diameter. Thick-walled dark brown chlamydospores are also formed. Spore formation is very free and sometimes, in the older cultures, the conidia develop below the tip of the conidiophores. They measure 15—20μ × 10—12·5μ.
2. *Thaxter's hard potato agar* (+6 Fuller's scale). Growth poor at first but later on fairly good. The medium becomes slightly yellowish near the margin in the beginning and then turns darker gradually. Aerial growth is moderate, dark olive grey in colour. The appearance of the growth is somewhat like that on nutrient

glucose agar, but less luxuriant. Conidia numerous, sometimes on the sides of the conidiophores, 22·5—30μ× 12·5—16·2μ in diameter. Chlamydospores are also formed.

3. *Wheat broth agar.* Growth profuse, nearly as good as No. 1. The medium in the beginning is slightly pink in colour along the margin, but the main portion is grey. After a few days, the marginal pinkish colour turns slightly yellow and the main portion darkens. Aerial mycelium is produced in a sufficiently large amount and almost fills the tube. Hyphæ subhyaline to greyish brown and up to 7μ in diameter. Spore formation copious and begins when the culture is only two days old. Conidia 2—5 at the tip of conidiophore, but often only one and occasionally up to 8 are noticed. Secondary sets of conidia are also frequently formed. They measure 25—35μ × 12·5—15μ.
4. *Wheat meal agar* (+2 Fuller's scale). The growth of the fungus is crowded or compact. First the medium gets pink towards the margin, then gradually changes into light greenish grey. This colour predominates for some time in the whole medium and then, as the culture ages, it changes into dark yellow. Hyphæ subhyaline to dark grey and up to 7·5μ in diameter. Spore formation fair and conidia 25—32·5μ × 12·5—15μ in diameter.
5. *French-bean agar* (+8 Fuller's scale). A good growth with abundant aerial mycelium almost filling the tube within 7 or 8 days. The medium is first grey, then dark in colour. Hyphæ remain either sterile or very few spores are formed, but there is a great development of chlamydospores. The conidia are 27·5μ long and 15μ broad.
6. *Nutrient glucose agar* (+5 Fuller's scale). Copious woolly aerial growth. Aerial hyphæ greyish brown in colour. The medium in the beginning becomes light pink and this later on turns into dark brown. Aerial hyphæ after some days change into olive brown. Spore formation begins when the culture is 3 or 4 days old and conidia are formed in large numbers. They measure 25—37·5μ × 12·5—20μ. Besides this formation of spores, chlamydospores of a dirty brown colour are produced in fairly large numbers.
7. *Rice meal agar* (+4 Fuller's scale). The growth is fair and slightly pink in colour as in the last medium. With age, the hyphæ become darker in colour. The margin of the medium changes to pinkish yellow. Spore formation poor. The conidia measure 22·5—37·5μ × 10—16·2μ.

8. *Jowar meal agar* (+2 Fuller's scale). Growth as in the last. After a few days the medium becomes light yellow in colour. Few chlamydospores occur. Conidia are formed in fairly large numbers. They measure 22—37·5μ×12·5—17·5μ.

9. *Jowar leaf juice agar.* The growth is almost submerged, but there is abundant spore formation. Conidiophores are often angularly bent and nodulose. The conidia measure 17·5—30μ×12·5—15μ.

10. *Barley meal agar* (+3 Fuller's scale). The growth is poor. The hyphæ are dark grey. The medium is dark yellow near the margin. Abundant spore formation takes place and the conidia measure 25—32·5μ×12·6—16·2μ.

11. *Litmus lactose agar* (+6 Fuller's scale). The growth is poor. With age, the red colour of the litmus changes into blue and then darkens, showing that the medium is becoming alkaline in reaction. Few chlamydospores are formed. Spore formation is poor and the conidia measure 22·5—32·5μ×10—16·2μ.

12. *Dextrose agar* (+2 Fuller's scale). Growth is poor. Aerial mycelium is little and of grey colour. Old cultures become slightly pink. No chlamydospore formation. Conidium formation poor. Conidia measure 25—30μ×12·5—15μ.

13. *Oat meal agar* (+2 Fuller's scale). Growth fair and crowded. No chlamydospore formation. Spores form in large numbers and measure 22·5—32·5×10—16·2μ.

14. *Glycerine agar* (+6 Fuller's scale). Very poor growth. The hyphæ are almost submerged and the medium turns pink in colour; later on the hyphæ become grey. A good many chlamydospores are formed. Conidium formation fair and conidia measure 22·5—32·5μ×10—15μ.

15. *Cellulose agar* (+9 Fuller's scale). Very poor and submerged growth in this medium. For the first few days there was little growth and a few chlamydospores were produced. Spore formation is fair ultimately and in measurement the conidia are 25—35μ×12·5—17·5μ.

16. *Starch agar* (+4 Fuller's scale). The growth in the beginning is poor, but after a few days it improves. The growth is sub-aerial with some submerged. The medium becomes dark grey. No chlamydospore formation takes place. Conidia in fairly large numbers and measure 20—30μ×10—16·2μ.

17. *Corn meal agar* (+2 Fuller's scale). The growth is quite good and is pink in the beginning, but later on it changes into dark grey.

The medium gradually turns yellow in colour. Spore formation copious as in wheat broth agar. In measurement the conidia are $22{\cdot}5$—$32{\cdot}5\mu \times 10$—15μ.

18. *Corn leaf juice agar* (+3 Fuller's scale). The growth is bad and almost entirely submerged. Very few spores are formed.
19. *Naegelis nutrient solution.* Growth very poor. Very little aerial mycelium.
20. *Cohn's nutrient solution.* As in the above, here also growth is poor with very little aerial mycelium.

From the study of the fungus in the above media it is found that some media are favourable for the formation of a large number of spores and some for the formation of chlamydospores; while some are good for both. A few media are unfavourable either for growth or formation of spores and chlamydospores. In some media spores are nearly of the same size as those found on the host under field conditions and in some they are much smaller. The perfect stage of the fungus does not occur on any of the above media, nor has it been found on the host.

(*d*) *The effect of reaction of media.* This experiment was run in duplicate using glucose agar. Twenty tubes were inoculated, two of each reaction, ranging from −15 to +30 Fuller's scale.*

TABLE I.

Tube No.	Reaction	Growth after 12 days	REMARKS
1	−15 Fuller's scale	Poor	Growth poor but spore formation copious.
2	−10 ,,	Fair	In the beginning poor but after a few days fair. Spore formation normal.
3	−5 ,,	Fair	Growth was a little more than in −10.
4	0 ,,	Good	Aerial growth in sufficiently large amount.
5	+5 ,,	Very good	Aerial growth more than in 0.
6	+10 ,,	Very good	Aerial growth more than in 0.
7	+15 ,,	Good	The growth in the beginning was poor.
8	+20 ,,	Fair	Aerial growth little.
9	+25 ,,	Poor	No spore formation.
10	+30 ,,	Very poor	In the beginning there was no growth. No spore formation.

* Media from +15 to +30 remained in the liquid condition on account of too much acidity.

These data show that this fungus prefers a reaction ranging between +5 and +10 Fuller's scale, but can withstand a considerable range either way.

6. ETIOLOGY OF THE DISEASE.

(*a*) *Formal proof of pathogenicity of Acrothecium Penniseti n. sp.* There is no doubt that this disease on *bajra* is due to this fungus as determined by the following points :—

1. The constant association of the fungus with the disease, and its isolation from typical diseased tissue of the host.

2. Healthy plants inoculated with pure cultures give characteristic signs of the disease. The penetration of the fungus was also noticed.

3. The fungus was reisolated from inoculated diseased spots and reinoculated on healthy plants and the disease was produced as before. The reisolated fungus was compared in culture with the fungus used for inoculation and was identical with it.

(*b*) *Details of inoculations.* The following are the details of the inoculations made on leaves and ears of *Pennisetum typhoideum* :—

Experiment 1. In the beginning of September 1919, 26 inoculations were made by placing a little mycelium and spores from a pure culture on either side of a number of leaves and leaf-sheaths ; these were kept in a moist chamber. After 24 hours almost all the leaves were discoloured and had become pale in the places where they had been inoculated, and after 48 hours on microscopic examination it was found that the mycelium had penetrated in the tissues. Conidiophores and conidia started coming out after 72 hours. The infected spots gradually increased in size and were like those found in the field.

Experiment 2. (15–9–19.) Nine leaves of a healthy shoot were inoculated on either side with spores and mycelium from a pure culture as already described, and the shoot was covered with a bell jar. A control was also kept. On the fourth day four leaves showed signs of infection in the inoculated places ; another spot appeared on the sixth day ; two more on the seventh and the remaining on the eighth day. In the beginning the infected spots became pale and then gradually turned yellowish brown and ultimately dirty brown. All the spots increased in size and in five or six days after infection conidiophores began to come out. The control was intact.

Experiment 3. (15–9–19.) Two healthy shoots with ears were inoculated in six places on leaves (either side) and in eight places on ears. A control was also kept. In this experiment one leaf took the infection within 48 hours, and on the fourth day three more showed infection. On the sixth day the remaining leaves were also found to be infected, showing the characteristic symptoms of the disease. All the inoculations made on spikelets of the ears were successful and the glumes became light brown. Conidiophores began to appear eight days after inoculations. The control was healthy.

Experiment 4. (18–9–19.) Twelve leaves and sheaths of a healthy young plant (about two months old) were inoculated on either side with spores and mycelium from a young culture. The plant was covered with a bell jar. There was also a control. In 24 hours 7 leaves showed sign of infection and the spots inoculated showed penetration of hyphæ. After 48 hours three more were infected and two of the former spots had increased in size. On the fourth day infection took place on the remaining leaves and conidiophores began to appear four days later. The control showed no sign of disease.

Experiment 5. (26–9–19.) Three shoots with ears were placed in small flasks containing water. Nine inoculations on leaves and nine on the spikelets were made. Three shoots with ears were kept as controls. All inoculations on leaves and ears were successful on the third day. The spots on the leaves increased very much in size and those on the ears also increased and infected the neighbouring spikelets. There was no sign of disease either on leaves or on the ears of the controls.

Experiment 6. (26–9–19.) Ten inoculations on either side of the leaves and leaf-sheaths of two healthy young plants were made; spores only being used and the spots inoculated were covered with sterile cotton wool. The plants were placed outside in rain. A control was also kept. Six leaves took the infection in 24 hours and the remaining in 48 hours. The control remained healthy.

Experiment 7. (26–9–19.) Twelve leaves of two healthy full-grown plants were inoculated and kept in the same way as Experiment No. 6. A control was also kept. Four inoculations were successful in 24 hours, two on the third day and the rest on the fifth day. The control was without any sign of the disease.

Experiment 8. (11–10–19.) Twelve inoculations were made on four ears (3 on each) and the ears were covered with bell jars. A control was kept. After 48 hours a woolly growth appeared in the places inoculated and this went on increasing and infecting the neighbouring spikelets. Within ten days all the four ears were completely covered with aerial growth. The hyphæ penetrated the glumes and palæ, and in most cases even the ovary. The control was free.

Experiment 9. (21–10–19.) Three ears were inoculated as above and a control was also kept. The result was as in the above experiment.

Experiment 10. (25–10–19.) Three ears were inoculated in 9 places and the inoculated spikelets were covered with sterile moist cotton wool. After three days the cotton wool was removed and the spikelets were found to have turned brown in colour and on examination showed the presence of hyphæ inside them. The control that was kept showed no evident sign of the disease.

Experiment 11. (28–10–19.) Seventeen leaves and five ears of six healthy shoots were inoculated and the spots covered with sterile cotton wool. All except the control got infected in a week.

Experiment 12. (28–10–19.) Five leaves and three ears of a grown up plant were inoculated and the inoculated spots covered with sterile moist cotton wool. All inoculations on leaves and ears were so successful as to produce the characteristics of the disease. The control kept was satisfactory.

(*c*) ***Results of inoculations.*** Altogether 106 inoculations on leaves (both sides) and leaf-sheaths, together with 40 on ears, were made, and all were successful. The results of the above experiments prove beyond doubt the parasitic nature of *Acrothecium Penniseti* on *Pennisetum typhoideum.*

TABLE II.

Summary of results of inoculations on Pennisetum typhoideum.

No. of experiment	Date	Where inoculated	Number of inoculations	Number infected	REMARKS
1	Beginning of September 1919.	Leaves	26	26	Leaves removed and kept in a moist chamber.
2	15–9–19	Leaves	9	9	Leaves on a shoot.
		Control	1	..	
3	15–9–19	Leaves	6	6	Leaves and ears on two healthy shoots.
		Ears	8	8	
		Control	1	..	
4	18–9–19	Leaves	12	12	Leaves on a plant.
		Control	1	..	
5	26–9–19	Leaves	9	9	
		Ears	9	9	Three shoots with ears.
		Controls	3	..	
6	26–9–19	Leaves	10	10	Two young plants.
		Control	1	..	
7	26–9–19	Leaves	12	12	Two mature plants.
		Control	1	..	
8	11–10–19	Ears	12	12	Four ears.
		Control	1	..	
9	21–10–19	Ears	3	3	Three ears.
		Control	1	..	
10	25–10–19	Ears	9	9	Three ears.
		Control	1	..	
11	28–10–19	Leaves	17	17	
		Ears	5	5	Six shoots with ears.
		Control	1	..	
12	28–10–19	Leaves	5	5	A mature plant.
		Ears	3	3	
		Control	1	..	

7. RELATION OF PARASITE TO HOST.

The examination of inoculated leaves shows that infection can take place either through a stoma or through any epidermal cell on either side of the leaf.

(*a*) *Infection through a stoma.* The hypha near a stoma gives out a narrow tube which after passing through it again swells up and resumes its usual size. It spreads a little in the sub-stomatal space and then passes on to other cells (Plate IV, fig. 1).

(*b*) *Infection by piercing the epidermis.* The infection can take place from any cell of the epidermis but is more common from the thin-walled motor cells (Plate IV, figs. 2—4). The hypha either directly penetrates the epidermis or under the cuticle parallel to the outer wall of the epidermis to some extent, and then goes down either into an epidermal cell or between the side walls of two cells to cells deeper in. Sometimes when it is passing between the side walls of two cells, it sends a branch into one of them. Sometimes after inoculation the hyphæ are found in large amount under the cuticle but none in the cells below. Generally, before entering, the hypha coming in contact with the cuticle swells up and gives out a narrow tube which after penetrating the epidermis again swells up. Frequently the hypha presses down the cuticle of an epidermal cell to effect an entrance. After entering it may branch and fill the epidermal cell with a mass of mycelium or may directly penetrate deeply into the tissue of the leaf by passing from cell to cell and ramifying both in the thin-walled parenchymatous and the sclerenchymatous cells, and later may enter the vascular bundles.

It is both intra and inter-cellular. Haustoria are not found. In passing from cell to cell the hypha gives out a narrow tube which pierces the wall and on entering the opposite cell again resumes its former thickness. The fungus can invade new areas by passing along the vessels of the xylem (Plate IV, fig. 6). It cannot penetrate the midrib directly, but generally infection takes place from hyphæ passing in through the motor cells just on either side of it. The intra- and inter-cellular hyphæ are very clearly seen in the midrib region, and here sometimes they spread more through the inter-cellular spaces which are found at the angles of two or more cells (Pl. IV, fig. 5) than through the cells. Frequently the fungus forms stromatic masses in the epidermal cells on both sides of the leaf, sometimes in quantity sufficient to rupture the cuticle. In sclerenchymatous cells and in the vascular bundles hyphæ often swell up to such an extent so as to fill the cavity.

The fungus kills the cells in advance of its growth, and penetration of the dead cells is evidently easier than of the living, since in the central dead portion of the spot hyphæ are found abundantly, but they are almost absent in the cells around the central dead portion.

After three or four days from infection conidiophores start coming out in clusters on both sides of the leaf through the stomata from a mass of mycelium lying in the sub-stomatal space. They even come out from the stomata on the midrib. When after inoculations infection is very vigorous they come out from the stromatic masses in the epidermal cells. It may be recalled here that in field conditions they always come out from the stomata.

8. Cross inoculation experiments.

In order to find out whether this fungus can attack other hosts which have been also found infected by species of *Acrothecium*, inoculations were made on *Andropogon Sorghum* and *Zea Mays*.

Leaves and ears of *Andropogon Sorghum* were inoculated with the *bajra* fungus, but no infection took place.

A large number of inoculations were made on the leaves and male inflorescence of *Zea Mays*, and it was observed that the *bajra* fungus can infect the male inflorescence, but has no effect on the leaves.

A. lunatum, Wakker, which is found on *Andropogon Sorghum* leaves and male inflorescences of *Zea Mays* at Pusa, can infect to some extent, under laboratory conditions, the young leaves of *Pennisetum typhoideum*.

9. Diagnosis.

The following is the diagnosis :—

Acrothecium Penniseti n. sp. Spots amphigenous on leaves and glumes; in size generally 2—5 cm. long and 0·5—1 cm. broad; dirty brown with yellowish margin. On the leaves more common along the edge and tip, and sometimes on the other parts including the midrib.

Fertile hyphæ rigid, erect, simple, 3—5 septate, straight or slightly bent; fasciculate or solitary; tip swollen or flexuous; olive brown to dirty brown with paler tips; base sometimes swollen. They are 68·4—145·4 μ long and 7·5—8·7μ broad.

Conidia borne acrogenously on the conidiophore, forming a group of 2—5 spores; clavate, pear-shaped or slightly bent, thick-walled, 2-3 septate, sometimes constricted at the septa; olive brown to dirty brown; 30·4—41·8μ long and 17·1—20μ broad. End cells lighter in colour; middle cell broader and deeper in colour.

On leaves and ears of *Pennisetum typhoideum* in India.

10. SUMMARY.

1. There are several species of *Acrothecium* known on various grasses, but none has hitherto been reported on *Pennisetum typhoideum*, and the present species does not agree with any of those previously described. It is a new disease caused by *Acrothecium Penniseti* n. sp.

2. It is found on ears, leaves and leaf-sheaths, and forms dirty brown spots with yellow margin.

3. Conidiophores arise in clusters through the stomata and spores are borne apically in fascicles of 2—5.

4. Infection can take place either through a stoma or by directly piercing an epidermal cell.

5. The fungus is cultivable on most artificial media but gives the highest development on wheat broth agar, potato juice agar, nutrient glucose agar, and on French-bean agar.

6. In culture secondary sets of conidia are formed either below the tip on the sides of conidiophore or above by the elongation of the latter.

7. In some media chlamydospores of a dirty brown colour are formed.

8. The growth is best on media having the reaction between +5 to +10 Fuller's scale but the fungus can withstand a wide range of reaction.

9. The parasitism of the fungus has been proved beyond doubt by numerous inoculations on leaves and ears.

10. The mycelium is both intra and inter-cellular and is found in all parts of the infected leaf.

11. Cross inoculations on male inflorescence of maize were successful while those on *Sorghum* gave negative results.

To Dr. E. J. Butler, Imperial Mycologist, under whose direction this work has been carried out, is due my grateful acknowledgment for his able advice and criticism.

APPENDIX.

1. Glucose meat-extract agar.

A	Peptone	1·0 grm.
	Sodium chloride	0·5 grm.
	Meat extract	0·5 grm.
	Glucose	4·0 grm.
	Water	100·0 c.c.
B	Agar agar	2.4 grm.
	Water	100·0 c.c.

2. Glycerine agar.

It was prepared by adding 10 c.c. of pure glycerine to the above medium in place of glucose.

3. Litmus lactose agar.

It was prepared by adding 2 grm. of c.p. lactose and 4 c.c. of blue litmus solution to medium No. 1 in place of glucose.

4. Starch agar.

To 400 c.c. of hot water 5 grm. of pure starch were added and boiled for two hours. When a starch solution of 250 c.c. was obtained, it was added to 250 c.c. of the following nutrient solution.

A	Potassium phosphate	1 grm.
	Magnesium sulphate	1 grm.
	Sodium chloride	1 grm.
	Ammonium sulphate	2 grm.
	Water	100 c.c.
B	Calcium carbonate	1 grm.
	Water	900 c.c.

A and B were mixed.

Starch solution	250 c.c.
Nutrient solution	250 c.c.
Agar	5 grm.

5. Dextrose agar.

Dextrose	2 grm.
Agar	3 grm.
Water	100 c.c.
Nutrient solution as for starch agar	100 c.c.

6. **Cellulose agar.**

Water	100 c.c.
Cellulose (Pure)	1 grm.
Nutrient solution as for starch agar	100 c.c.
Agar	2 grm.

7. Potato juice agar.

75 grammes of potato were cooked in a water bath for half an hour and the juice was filtered in a fine cloth, and to it was added 5 grammes of agar and sufficient water to make the whole 250 c.c.

8. Thaxter's hard potato agar.

125 grammes of sliced potato were cooked for half an hour in 500 c.c. of water. It was filtered in a fine cloth, and water was added to restore the original volume. To this was added 10 grammes of glucose and 15 grammes of agar and boiled for two hours, cleared, filtered and autoclaved.

9. Jowar (*Andropogon Sorghum*) agar.

One ounce of *jowar* seeds were powdered and boiled in 150 c.c. of water for two hours. The boiled mixture was filtered in a wire gauze strainer and to it 7·5 grm. of agar added and sufficient water to make the total 500 c.c.

10. Oat meal agar.

15 grammes of quaker oat meal were mixed in 200 c.c. of water and boiled. Filtered in cloth, squeezed out the content and to it 2 grammes of agar added.

11. French-bean agar (50–10–500).

50 grammes of powdered French-bean were boiled in water for one hour, filtered with wire gauze strainer and 10 grammes of agar added and water sufficient to make the total 500 c.c.

12. Corn meal agar.

13. Wheat meal agar.

14. Rice meal agar.

15. Barley meal agar.

All these were prepared as French-bean agar.

16. Jowar leaf juice agar (30–3–200).

30 grammes of leaves of *Andropogon Sorghum* were boiled for one hour in a water cooker. Filtered in a cloth and to it 3 grammes of agar added and water enough to make it to 200 c.c.

17. Maize leaf agar.

It was prepared as the above medium, only, in place of *jowar* leaves, *Zea Mays* leaves were used.

18. Wheat broth agar.

Agar	1·2 grm.
Wheat flour	150·0 grm.
Magnesium sulphate	0·5 grm.
Potassium nitrate	1·0 grm.
Glucose	5·0 grm.
Water	1000·0 c.c.

Filtered and sterilized on three consecutive days at 100°C.

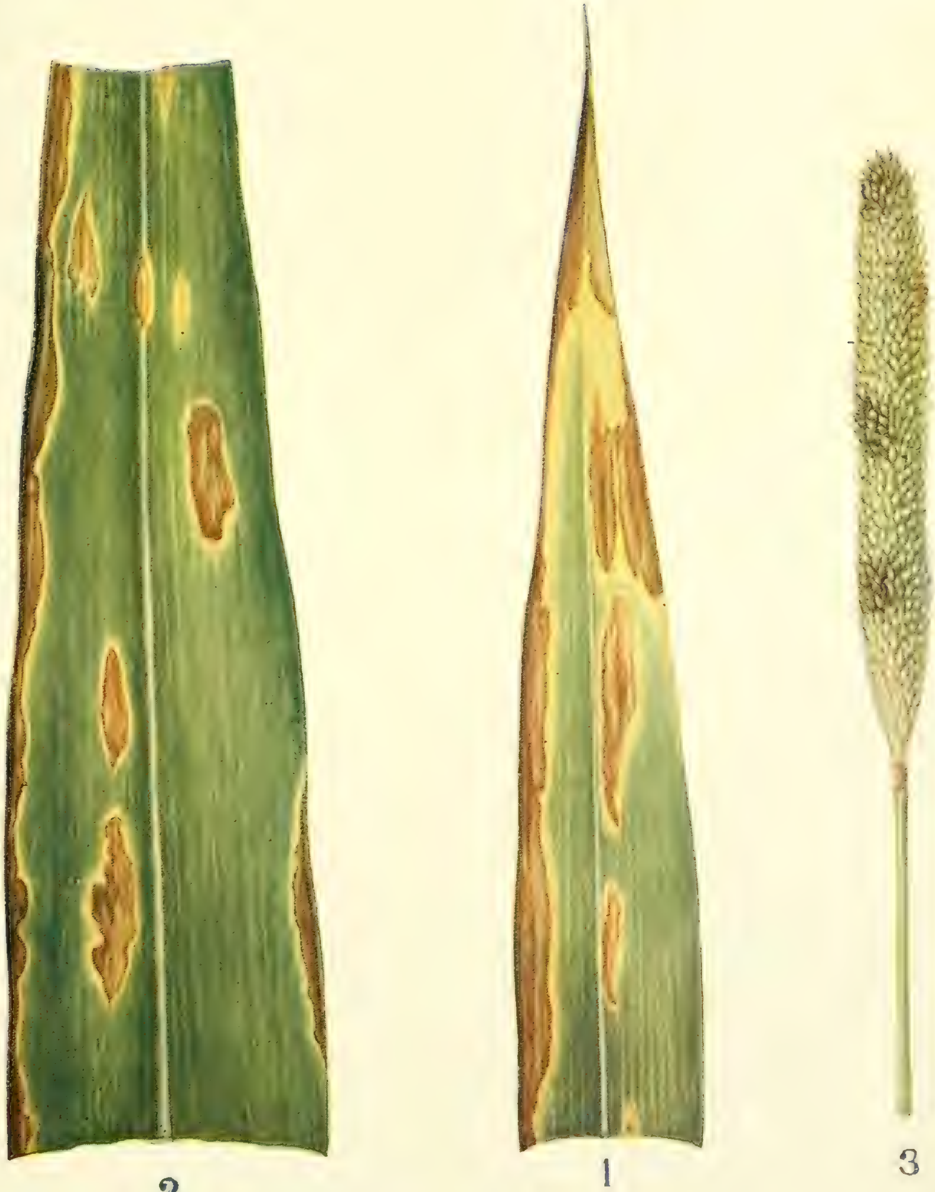
19. Naegeli's nutrient solution.

Calcium chloride	0·1 grm.
Magnesium sulphate	0·2 grm.
Dipotassium phosphate	1·0 grm.
Ammonium tartrate	10·0 grm.
Distilled water	1000·0 c.c.

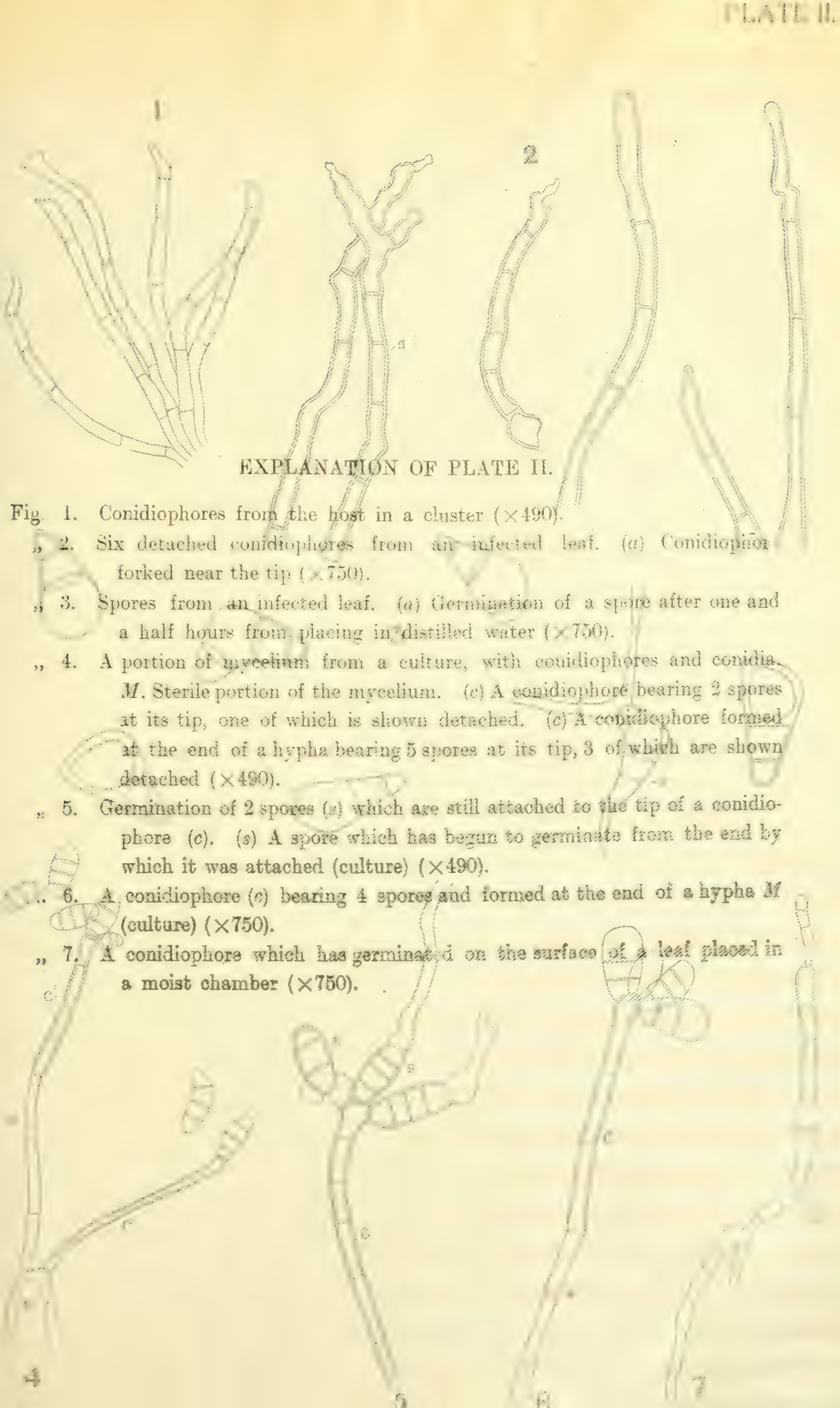
20. Cohn's nutrient solution.

Distilled water	1000·0 c.c.
Acid potassium phosphate	5·0 grm.
Magnesium sulphate	5·0 grm.
Neutral ammonium tartrate	10·0 grm.
Potassium chloride	0·5 grm.

PLATE I.



ACROTHECIUM ON PENNISETUM TYPHOIDEUM.



EXPLANATION OF PLATE II.

Fig. 1. Conidiophores from the host in a cluster (×490).

" 2. Six detached conidiophores from an infected leaf. (*a*) Conidiophor forked near the tip (×750).

" 3. Spores from an infected leaf. (*a*) Germination of a spore after one and a half hours from placing in distilled water (×750).

" 4. A portion of mycelium from a culture, with conidiophores and conidia. *M*. Sterile portion of the mycelium. (*c*) A conidiophore bearing 2 spores at its tip, one of which is shown detached. (*c*) A conidiophore formed at the end of a hypha bearing 5 spores at its tip, 3 of which are shown detached (×490).

" 5. Germination of 2 spores (*s*) which are still attached to the tip of a conidiophore (*c*). (*s*) A spore which has begun to germinate from the end by which it was attached (culture) (×490).

" 6. A conidiophore (*c*) bearing 4 spores and formed at the end of a hypha *M* (culture) (×750).

" 7. A conidiophore which has germinated on the surface of a leaf placed in a moist chamber (×750).

PLATE II.

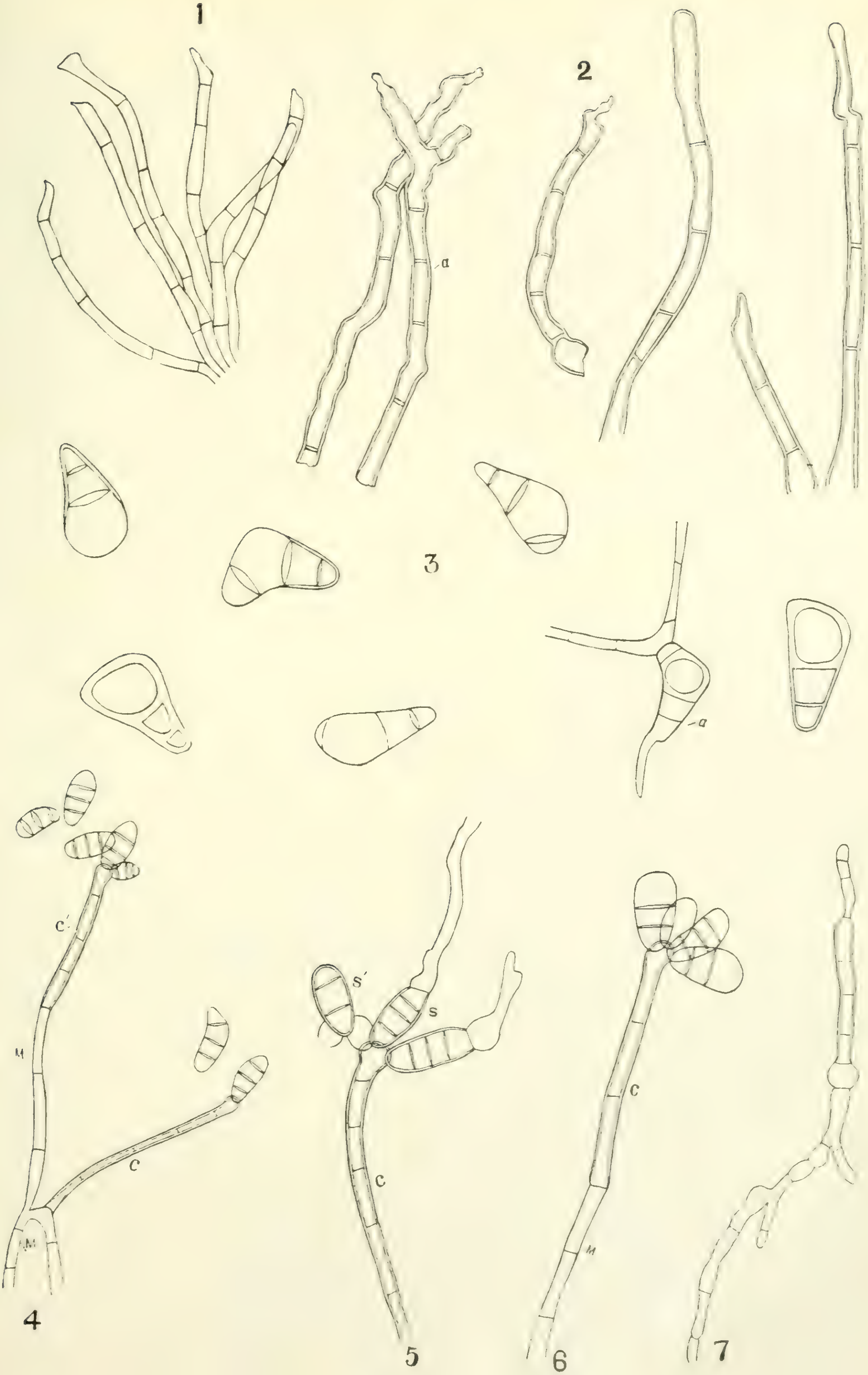

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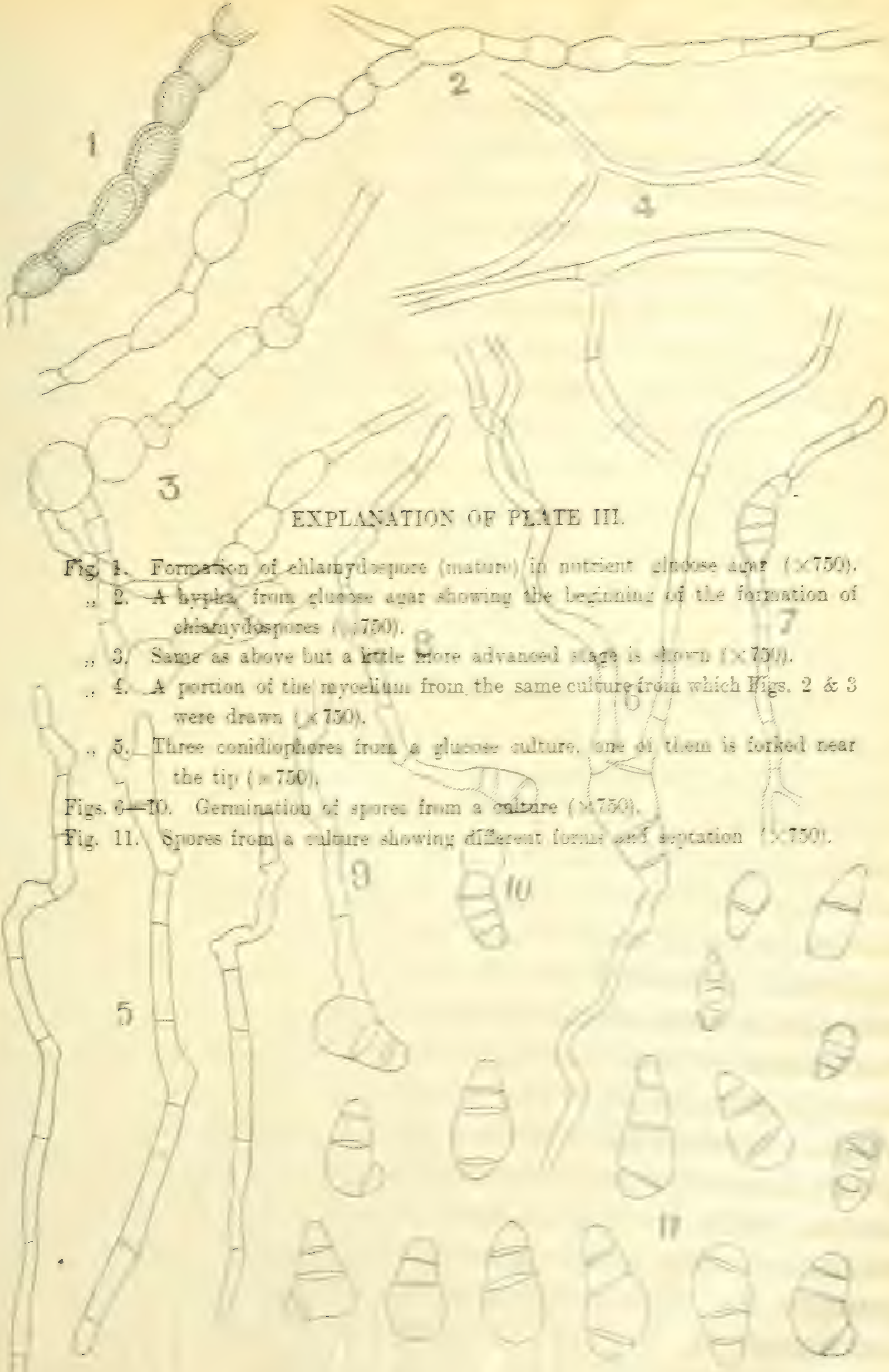
PLATE III.



EXPLANATION OF PLATE III.

Fig. 1. Formation of chlamydospore (mature) in nutrient glucose agar (×750).

„ 2. A hypha from glucose agar showing the beginning of the formation of chlamydospores (×750).

„ 3. Same as above but a little more advanced stage is shown (×750).

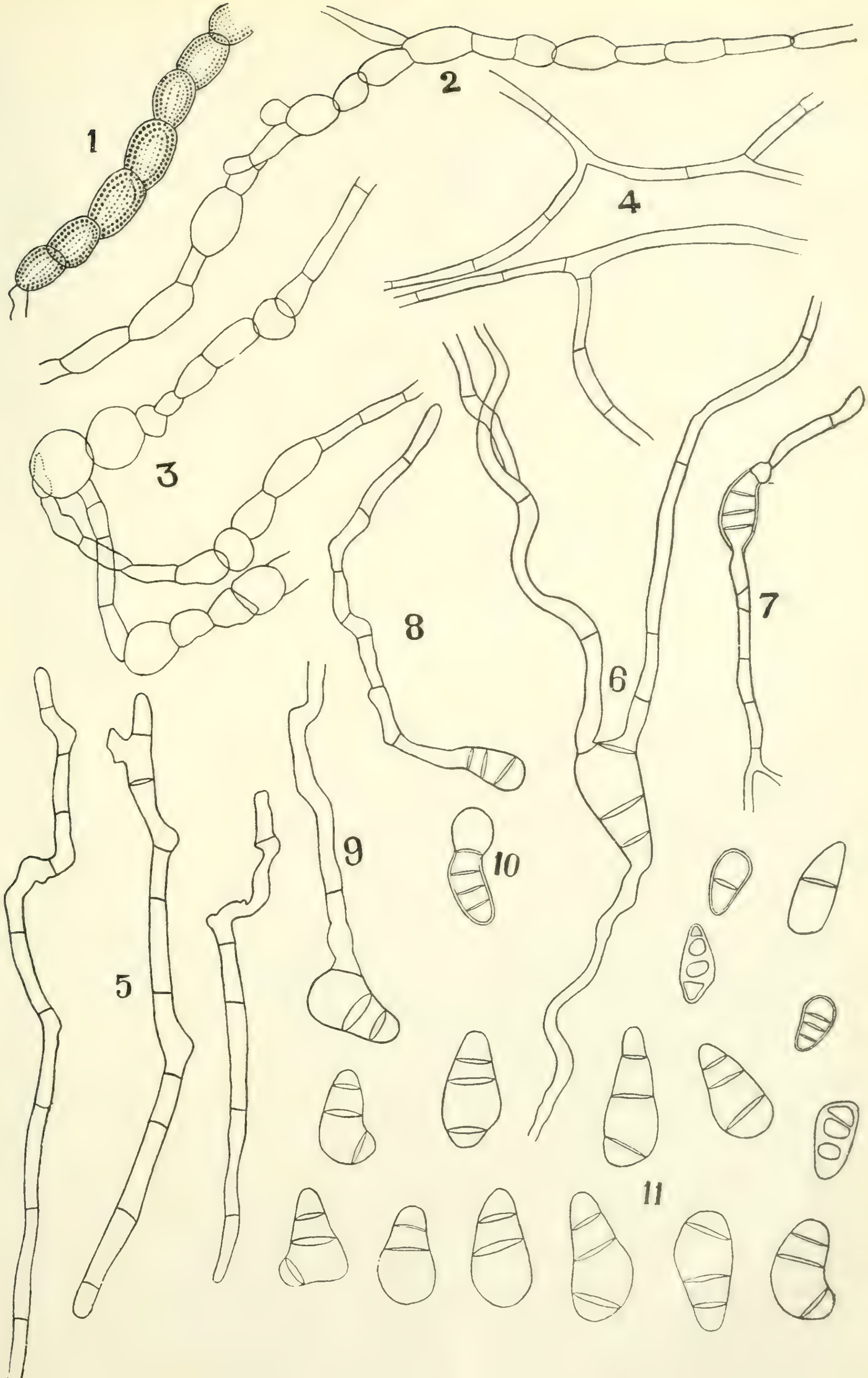
„ 4. A portion of the mycelium from the same culture from which Figs. 2 & 3 were drawn (×750).

„ 5. Three conidiophores from a glucose culture, one of them is forked near the tip (×750).

Figs. 6—10. Germination of spores from a culture (×750).

Fig. 11. Spores from a culture showing different forms and septation (×750).

PLATE III.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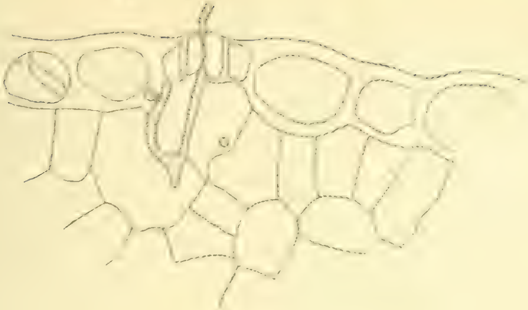

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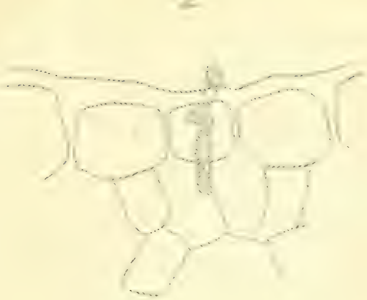

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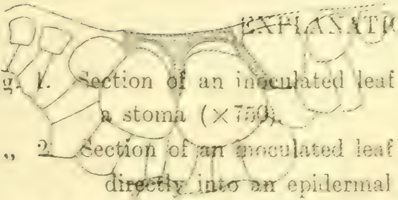

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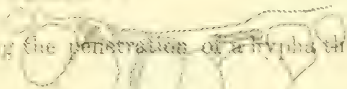


EXPLANATION OF PLATE IV.

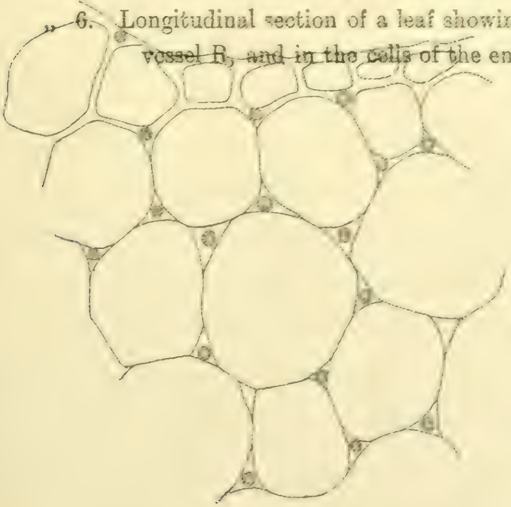
Fig. 1. Section of an inoculated leaf showing the penetration of a hypha through a stoma (×750).

„ 2. Section of an inoculated leaf showing the penetration through the cuticle directly into an epidermal cell (×750).

Figs 3 & 4. Sections of an inoculated leaf from different places showing the presence of hyphæ under the cuticle after penetration and in some places forcing their way through the side walls of two epidermal cells into cells deeper in (×490).

Fig. 5. Section of the midrib (upper side) of an infected leaf showing hyphæ in the inter-cellular spaces (×750).

„ 6. Longitudinal section of a leaf showing the presence of hyphæ in a reticulate vessel R, and in the cells of the endodermis H (×490).



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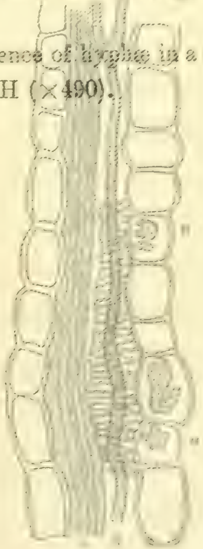

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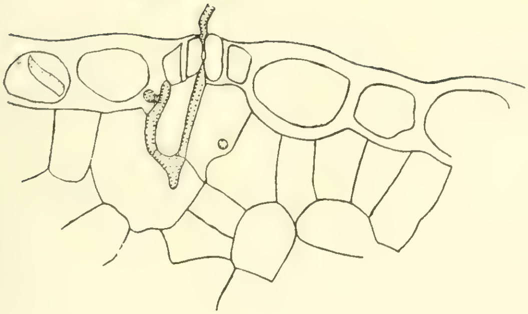

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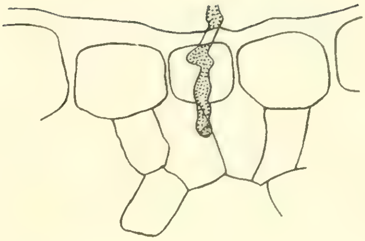

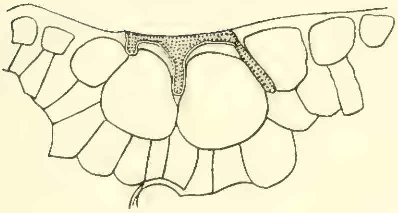

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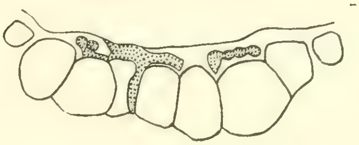

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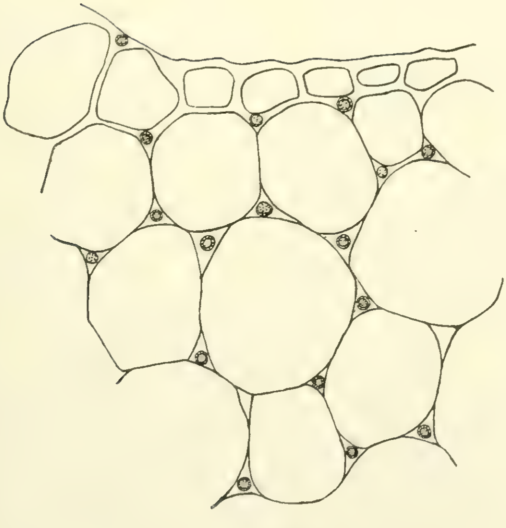

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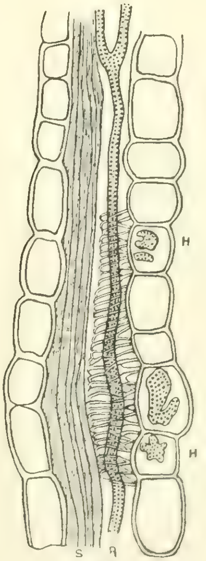

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BY

MAGANLAL L. PATEL, B. Ag

Cotton Supervisor, Gujarat

AGRICULTURAL RESEARCH INSTITUTE, PUSA

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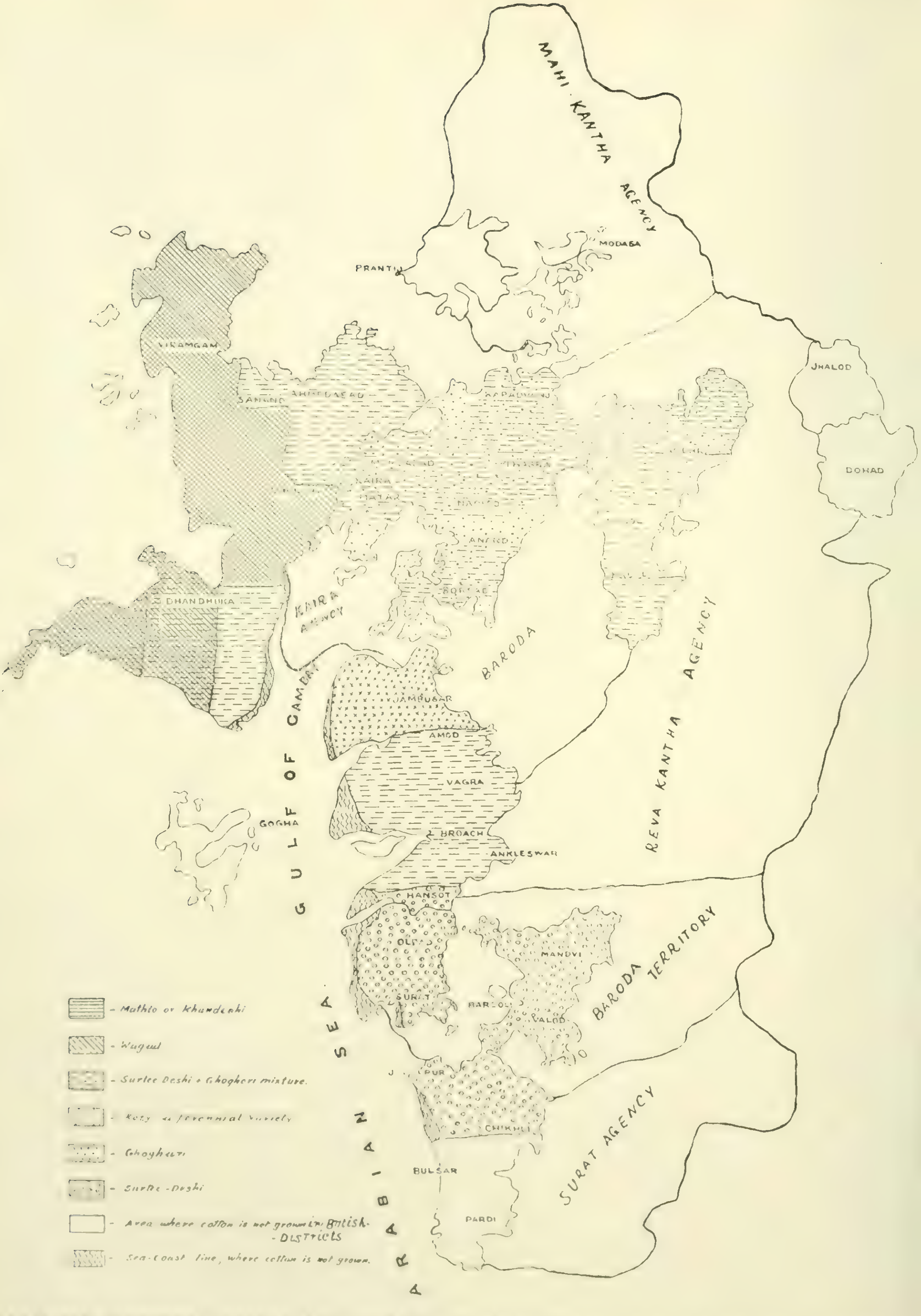
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- Mathio or Khandeshi
- Wagad
- Surtee Deshi + Ghogheri mixture.
- Rozy as perennial variety
- Ghogheri
- Surtee - Deshi
- Area where cotton is not grown in British - Districts
- Sea-Coast line, where cotton is not grown.

MAP OF BRITISH GUJARAT SHOWING VARIETIES OF COTTON GROWN.

STUDIES IN GUJARAT COTTONS, PART I.

BY

MAGANLAL L. PATEL, B.Ag.,

Cotton Supervisor, Gujarat.

[Received for publication on the 3rd September, 1920.]

I. General considerations.

Gujarat forms perhaps the most famous centre for Indian cotton growing. It has been renowned almost from the beginning of the Indian cotton trade, and so long ago as 1790, the annual production of Gujarat, including Bhavnagar, was 33,712,000 lb. or over 42,000 bales of our present measure, of which 26,656,000 lb. or over 33,000 bales were exported. Since that time the cultivation and production of cotton have extended, and Gujarat has become the home of two of the best known commercial types of Indian cotton, the " Broach " and the " Dhollera," and although, as we shall show, the cotton corresponding to these terms has varied very frequently and very largely, yet these names have for several generations indicated some of the best types of cotton that India has been able to produce. It is not, however, our intention in the present place to give a description of the history of Gujarat cottons and the types of plant which have produced them at different periods, but it will be necessary to review what is at present known of the varieties of cotton grown in different parts of the area, in order to make our studies of the individual types intelligible and clear.

The cottons grown in Gujarat at the present time belong to three different species: *Gossypium herbaceum,* which is by far the most extensively grown and which may be considered to give its character to the area, *Gossypium neglectum,* probably a recent introduction, grown to a considerable extent only in one corner of the area, and *Gossypium obtusifolium,* a perennial cotton grown sporadically over a large area of

Northern Gujarat, but the extent of whose cultivation is tending to decline. A map showing the varieties of cottons is attached herewith as Plate I. Plate II shows the area and the percentage of cotton area to the total cultivated area.

The variety of *Gossypium obtusifolium*, which is grown, as we have said, sporadically over a large part of the Kaira District and the northern portion of the Godhra Taluka in the Panchmahals, is locally termed "Rozi" or "Jadia" cotton. This type has been often described. Middleton[1] in 1895 characterized it as follows and his description fairly represents its special features :—

"This is a perennial, cultivated upon light soils in Northern Gujarat. A tall much branched shrub, 6 to 8 feet high, it readily runs wild, and in hedgerows assumes a climbing habit.

"This cotton is cultivated as a mixture crop, one row being sown between ten or twelve rows of some cereal. In the first season it yields little or no cotton: in the hot weather it is cut down to one foot of the ground, in the second monsoon it grows luxuriantly and produces a full crop in the following hot season. The cotton in subsequent years is of coarser quality than that of the second, and the plant is usually rooted out at the end of the third or fourth season, but it is occasionally allowed to grow for six or seven years. When growing wild in hedgerows the cotton turns yellow, and very short in staple ; the fuzz at the same time becomes long. *Rozi* is markedly different from the annual cottons and does not seem to hybridize with them. It strongly resembles *Gossypium arboreum*, the chief difference being a yellow flower and the absence of the marked reddish tinge possessed by this species."

As has already been stated, the cultivation of this cotton is declining. It produces a lint of fairly long staple, which is, however, very coarse, and is almost entirely used locally in Northern Gujarat. Its value is much decreased owing to the unripe condition in which it is usually picked. It has probably little or no future, and while it will continue to be grown, yet its cultivation hardly affects the larger interests of cotton growing in the province. It occupies nearly 7,000 acres in the Kaira District.

The type of *Gossypium neglectum*, which has in recent years extended over the greater part of Kathiawar, and especially of Bhavnagar, is known as "Mathio." In the British districts of Gujarat, it is found to any great extent only in the western portions of the Dhandhuka Taluka and the

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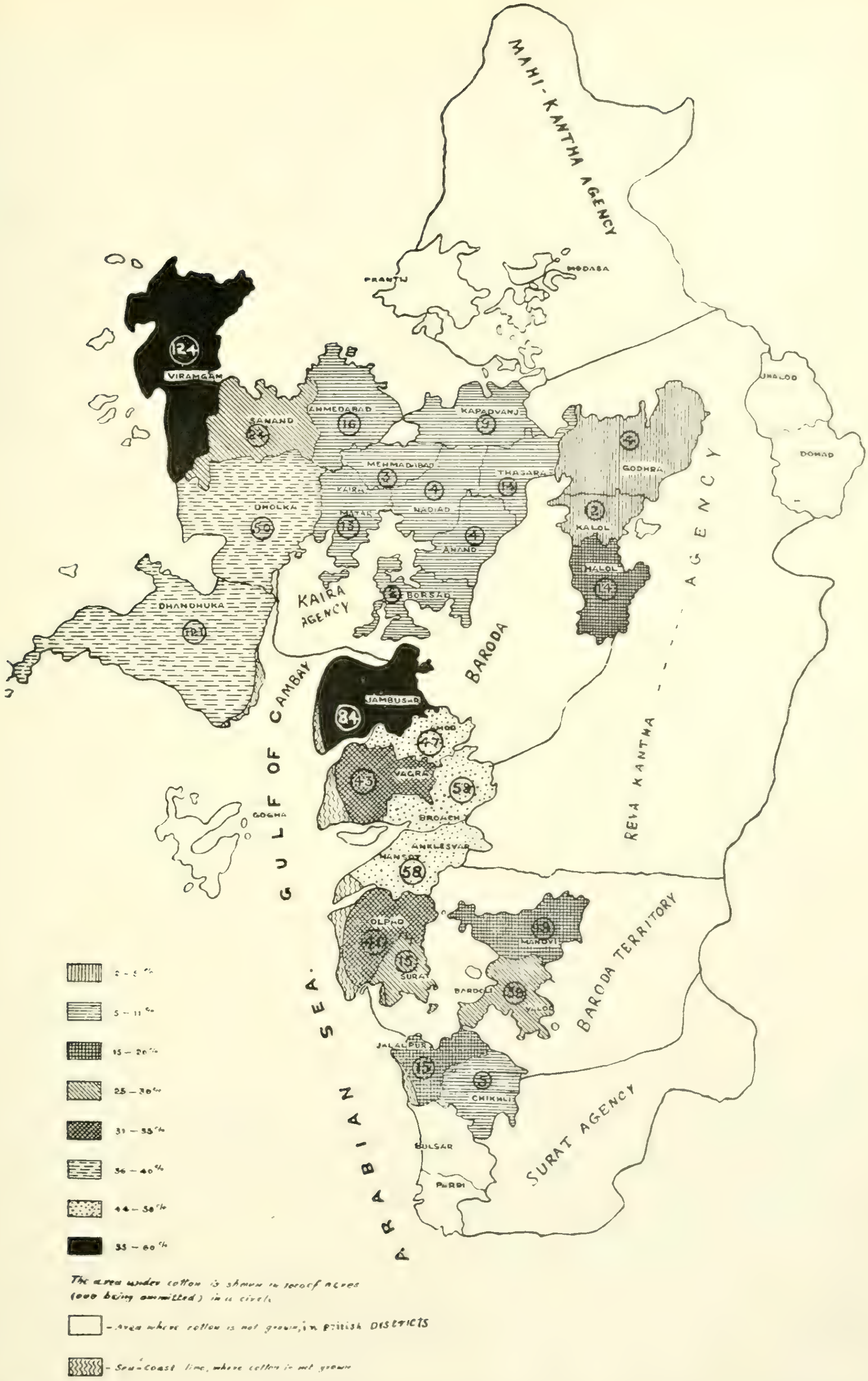
[1] *Agricultural Ledger*, 1895, no. 8.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BARODA TERRITORY
JALALPUR
15
5
CHIKHLI
BULSAR
PARDI
SURAT AGENCY
ARABIAN SEA.
2 – 5 %
5 – 11 %
15 – 20 %
25 – 30 %
31 – 35 %
36 – 40 %
44 – 50 %
55 – 60 %
The area under cotton is shown in 1000's of acres (000 being ommitted) in a circle
– Area where cotton is not grown, in British DISTRICTS
– Sea-coast line, where cotton is not grown

Map of British Gujarat showing the area under Cotton and the percentage of total cultivated area in 1916-17.

Gogha Petha of the Ahmedabad District. Its introduction seems to have been quite recent, and it has probably come from Khandesh. Prior to the great famine of 1899–1900, it was, according to Middleton[1], grown to a very limited extent in Bhavnagar, but its extensive adoption dates from about 1900. This adoption seems to have resulted from the fact that it will grow with less rainfall and in lighter soils than the varieties of *Gossypium herbaceum* formerly produced, and because it ripens earlier and hence enables the cultivators to realize their crop and pay their land revenue without recourse to a money-lender. Its extension, however, in the first years was slow, and it is barely mentioned by Gammie in his description of Indian cottons published in 1905. Since that time, however, its cultivation has increased enormously in Kathiawar, but it has been adopted only in the areas already mentioned in British Gujarat. Moreover, it does not show much sign of spreading further, as it is found that in the lighter soils of Northern Gujarat it has a tendency to ripen later, to decrease in ginning percentage and to yield less than *herbaceum* cottons under irrigation. The actual portion of British Gujarat which it occupies is shown in Plate II, where its area is 27,000 acres. It rarely occurs as a mixture in the field, except to a very small extent, with *Wagad* and *Lalio* cotton (*see* below).

But by far the greater part of Gujarat is cultivated with various varieties of *Gossypium herbaceum*, and it is to this species that its cottons owe their special reputation and character. The description of these varieties, their characters, and the areas they occupy, is, however, in considerable confusion, and nearly every authority seems to have adopted a different arrangement of them. We shall take as the basis of the following short account, the descriptions given by Gammie in 1903. He first divides the types of *Gossypium herbaceum* occurring in Gujarat into two groups as follows :—

" *Section A.* Bolls spherical, with broad valves, splitting so slightly when ripe that the cotton does not emerge. *Wagad* or *Wagadia* and *Sakalio*, five to six feet in height, cotton copious, but rather coarse, staple $\frac{5}{8}$ inch. Bolls with a very short point, but occasionally narrowed into a long one, mostly three-celled, dimensions average one inch by one inch.

" *Section B.* Taller and more compact plants than in the first section ; bolls more distinctly trigonous, narrower and pointed. Valves of ripe boll strongly reflexed so that the cotton is pendulous : bracteoles not so distinctly spreading.

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[1] *Agricultural Ledger*, 1895, no. 8.

"*Lalio, Kanmi.* Bolls 1¼ by ⅞ inch, cotton fine, adhering only slightly to seed, staple ⅝ inch.

"*Kumpta, Broach.* Size and habit of *Lalio*, but more hairy, and some of the bolls rounder but smaller, 1⅛ by ⅝ inch.

"*Goghari*, similar in most respects to *Wagadia*, but the plants are more spreading and the bolls open out like those of *Lalio*."

It is needless to follow the various modifications of the classification which have been given by different writers, but if we put together the essential facts as given by each of them, and combine them with our observations, we can indicate the following three clearly distinct types now cultivated in Gujarat :—

1. *Wagad* (*Wagadia, Dhumadia, Sakalio, Dabalio*) is a small branched bush, usually standing eighteen to thirty inches high, much less hairy than *Broach deshi*. The young stems, petioles, etc., are moderately thickly covered with simple hairs. Stellate hairs are large and numerous on the young leaves, few on the older leaves, which are almost glabrous and have a shining oily appearance. Stems, branches and petioles are of a deeper red in the upper surfaces than with *Broach deshi*. Leaves three to five lobed, cordate, half segmented or less. Lobes ovate to broad ovate, constricted at the base ; the lobes of the leaves on the younger branches are broad, obtuse, leathery and not constricted at the base. The spreading habit of the bracteoles is seen in all the annual cottons of Gujarat, but is most marked in *Wagad*, where they often begin to spread when the flower is opening. Bolls are smooth, globose usually, but sometimes tapering, mostly three-celled, and do not open fully when ripe, so that they are forced open by hand when removing the *kapas*. The lint is dull, white and coarser than *Broach deshi* and about equal in staple to the latter.* The seeds are rather large in size, oval in shape with a distinct hook at the tip, five to eight per cell and covered with fuzz.

The primary fruiting branches are stronger in *Wagad* than in other types of *herbaceum* cotton, while the axillary limbs develop later. Hence a larger proportion of the bolls are borne on the primary fruiting branches than in other Gujarat varieties. *Wagad* is the earliest flowering *herbaceum* but the flowering lasts a very long time, and the ripening is slow. The plant requires less moisture than the other varieties, and takes eight months to ripen. It is grown on slightly saltish land and its distribution in Gujarat reflects this feature. In British Gujarat, it nearly occupies 248,000 acres.

2. *Broach deshi* (*Lalio*) is a small shrub usually three to four feet high but varying greatly in size according to the soil. The whole plant is

*Most of the description is taken from Middleton (*loc. cit.*).

generally hairy, the young leaves and bracteoles pubescent, hairs stellate or three to four branched. The petioles, leaf ribs and peduncles villous, hairs simple, though a few stellate or branched hairs occur on the ribs. The leaves are very variable, cordate. The lower and larger leaves are five, six or seven lobed, the upper leaves three to five lobed, half or less than half segmented. The middle lobe is ovate, acute, mucronate and constricted at the base. The stipules are persistent, linear, and those in peduncles markedly unequal, one of them oblique, secondary or tertiary ovate, truncate, toothed and the other lanceolate-acuminate. The bolls are not usually smooth, of all shapes, usually three-celled, seldom two or four-celled, and they open fully when ripe, the valves being highly recurved on the edges. The lint adheres loosely to the seed, and is fine creamy-white, silky and of good staple. The seeds are smaller than in *Wagad* cotton and covered with whitish fuzz, usually six to seven per cell, seldom eight to ten.

So far as the branching is concerned, the limbs are more developed than in *Wagad*, and the axillaries arise earlier and are more numerous than in the latter variety. The flowering characters vary very largely, but the flowers appear later than in *Wagad* though the flowering is over sooner.

3. *Goghari* only differs from *Broach deshi* as regards the boll characters, and those of the seed and lint. These are described fully later as given by Middleton (page 81) and as observed by me (page 83).

These three types are the only ones which can, we think, be distinguished among the *herbaceum* cottons of Gujarat. They will be found mixed and hybridized in every proportion in almost every part of the province, and it is comparatively rare, except in very restricted areas, to find any of them in a perfectly pure condition. The *Wagad*, however, can be found relatively pure in a tract lying to the extreme north-west of British Gujarat in the Ahmedabad District, and on the borders of Kathiawar. The best centres for gettng pure *Wagad* cotton are, perhaps, Viramgam and Bavla. Again the only centre where *Broach deshi* can now be found relatively pure is in certain parts of the Surat District in the extreme south of the cotton area of Gujarat. The best centres for getting pure types are Jalalpor, Vedchha and Bilimora. The third variety, the *Goghari*, is found in the purest condition in the northern part of the Broach District, in the Jambusar Taluka. All the rest of Gujarat grows a mixture of types, and this is sometimes called *Kahanmi* or *Kanvi*, sometimes *Broach*, sometimes *Lalio*, sometimes *Amli*, while there are dozens of other local names. Its characters vary with the extent of the mixture and of the constituents. Until recently *roach deshi* decidedly predominated everywhere, but in the last few years the extent of the mixture with *Goghari* has generally increased. The Indian Cotton Committee record the following proportions in the mixture in different areas :—

District		* Percentage mixture of		
		Wagad	*Broach deshi*	*Goghari*
AHMEDABAD				
(1) Dhollera	(*Lalio*)	10·7	89·3	..
(2) Do.	(*Wagad*)	90·0	10·0	..
(3) Sanand	(*Lalio*)	2·7	97·3	..
(4) Do.	(*Wagad*)	87·0	13·0	..
(5) Viramgam	(*Deshi*)	100·0	..	..
(6) Do.	(*Lalio*)	..	41·7	58·3
KAIRA				
(7) Thasra	(*Kahanmi*)	..	60·8	14·2†
(8) Mehmadabad	Do.	..	54·8	45·2
(9) Matar	Do.	..	52·2	47·8
PANCHMAHALS				
(10) Kalol	(*Kahanmi*)	..	48·6	
BROACH				
(11) Ankleswar	(*Deshi*)	..	63·6	36·3
(12) Jambusar	(*Goghari*)	..	7·9	92·1
(13) Broach	(*Deshi*)	.	52·4	47·4

In spite of this condition of hopeless mixture, the three types can be traced throughout, and though hybridized and rehybridized again and again the plant and produce can always be referred to one or other of the descriptions given above.

It would be interesting to connect the proportion of these three types of *herbaceum* cotton with conditions of climate and soil, but though a few general indications can be given, the time is not yet ripe nor our inquiries sufficiently advanced to come to any but the most provisional conclusions in the matter.

In the first place, however, it is fairly clear that *Wagad* cotton dominates the situation only where the soil has a tendency to be saltish and where the rainfall is likely to be deficient. The soil may be either heavy or light. It is stated, though it is not equally certain, that the tracts, which grow *Goghari* best and where it yields more highly than any other variety of *herbaceum* cotton in Gujarat, are, where the soil is moderately light, of a

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* The terms used by the Cotton Committee have been modified to suit our classification.

† Also contains 25 per cent Rozi cotton.

besar or *goradu* type with a deep subsoil. But *Goghari* seems extremely adaptable, and is capable of flourishing, as well as *Broach deshi,* over the greater part of Gujarat, as is illustrated by its general extension in recent years.

II. GOGHARI COTTON.

1. *History of* Goghari *cotton.*

Goghari cotton, the extension of cultivation of which in Southern Gujarat, has been so disastrous for the quality of the staple in this part of India, has only been recognized as a separate type in very recent years. Where it came from we do not know. Its name would suggest that it originally was brought from Gogha, a part of the Ahmedabad District in Kathiawar, to the south of Bhavnagar, and that from there it may have been carried across the Gulf of Cambay to the Jambusar Taluka of the Broach District, where it is now grown in its purest form. But of this there is no direct evidence, and the first notice of this cotton occurs in 1891. In that year in a communication to the Bombay Trades Association[1] the following statement was made :—

"The only foreign seed introduced in Broach was the *Goghari* seed. That seed has been brought into Broach District during the last fifteen years, and the cotton produced from that seed was of an inferior quality. His firm first sent a consignment of this cotton home ; it was reported upon as harsh, deficient in staple, but of good colour and fine class. But since the *Goghari* seed has been acclimatized, the result was that the *Goghari* (seed) cotton had been passing in Liverpool as fine machine-ginned *Broach,* with an allowance of 1/32*d.* to 3/32*d.* per pound of the class, but when shipped as *Fully Good Broach* with mutual allowance terms, it fetched 1/8*d.* to 3/16*d.* per pound on the class sold. This *kapas* paid the *raiyat* because the lint outturn was better."

A few years later the variety was definitely established as a recognized type of cotton cultivated in the northern part of the Broach District. Middleton[2] in 1896 describes it as follows :—

"In *Goghari* the bolls are globose, and larger than those of *deshi.** The segments of the capsules are broad and do not recurve when the fruit is ripe. The lint hairs surrounding each seed separate readily from those of the adjoining seed, and do not cling as in *deshi.* The seeds are larger and darker in colour and have more fuzz. The wool (*i.e.,* lint) adheres more firmly to the seeds, is whiter, crisper, coarser, and more abundant. It is supposed to be a cross between the two cottons of *herbaceum,* namely, *Broach deshi* and *Wagad. Goghari* and *Broach deshi* seem to cross readily, and plants intermediate between the types are very common.

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[1] Extracts from the *Proceedings of the Cotton Trades Association,* July 31, 1891 : Communication by Messrs. Narandas Rajaram & Co.

[2] *Agricultural Ledger,* 1895, no. 8.

* By *deshi,* ordinary *Broach deshi* cotton is meant.

" *Gundi Goghari* plants are smaller with numerous bolls. The cotton is better in quality than is *Goghari* proper. This is believed to be an intermediate form between *Goghari* and *Kahanmi.* "

Some of these statements seem equally true to-day. In other matters the cotton seems to have considerably changed its character. We will, however, indicate a little later in what ways the present day typical *Goghari* cotton differs from what Middleton describes.

Eight years later Gammie[1] published his description and classification of the Indian cottons, but the following is his only reference to this variety :—

" It is similar in most respects to *Wagad,* but the plants are more spreading and the bolls open out like those of *Lalio.*"

In a later report[2], however, he states that *Goghari* exists as an appreciable mixture in *Broach,* but not in *Surat* cotton. In the neighbourhood of the Broach District, he quotes a case where *Goghari* occurred to the extent of 14 per cent. in the mixture grown.

He says, moreover, that " in *Goghari* the seed is larger than that of *Broach deshi,* and the cotton is more adherent so that it is more difficult to gin. The fuzz is white while that of *deshi* is brown." We will consider later how far these observations agree with ours.

2. *Characteristics of* Goghàri *cotton.*

None of these references to *Goghari* cotton had hitherto given a really recognizable description of the variety with which we are dealing. It is, however, very distinct, and in the relatively pure form in which it occurs in the Jambusar Taluka of the Broach District it can be recognized easily when growing, after the bolls have opened, and also in the seed cotton or even in the seed. So far as the plant itself is concerned, a critical study for a number of years has, however, failed to indicate any constant feature by which *Goghari* plants can be distinguished from ordinary plants of *Broach deshi* up to the time of the opening of the bolls. The form and branching of the plants (and the form of the leaves) are similar, the manner

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[1] The Indian Cottons, 1905.

[2] *Report of the Imperial Cotton Specialist,* 1914–1915.

PLATE III.

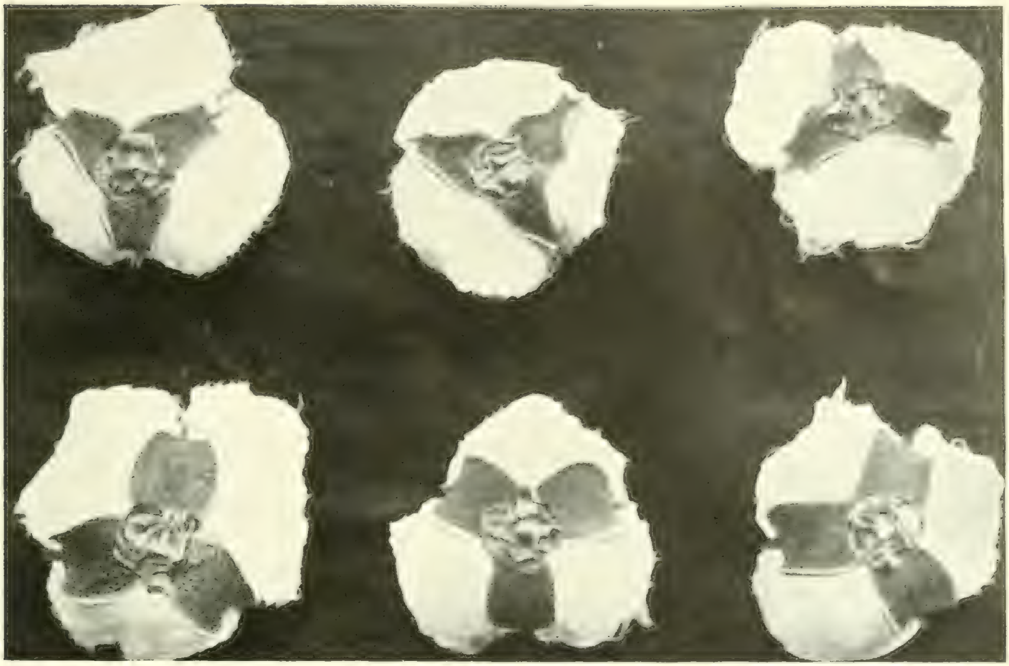


Fig. 1. *Upper row.* Broach Deshi, showing the recurving at the sides giving wide opening, due to which the cotton hangs down.

Lower row. Goghari, showing no recurvature, thus having less wide opening.

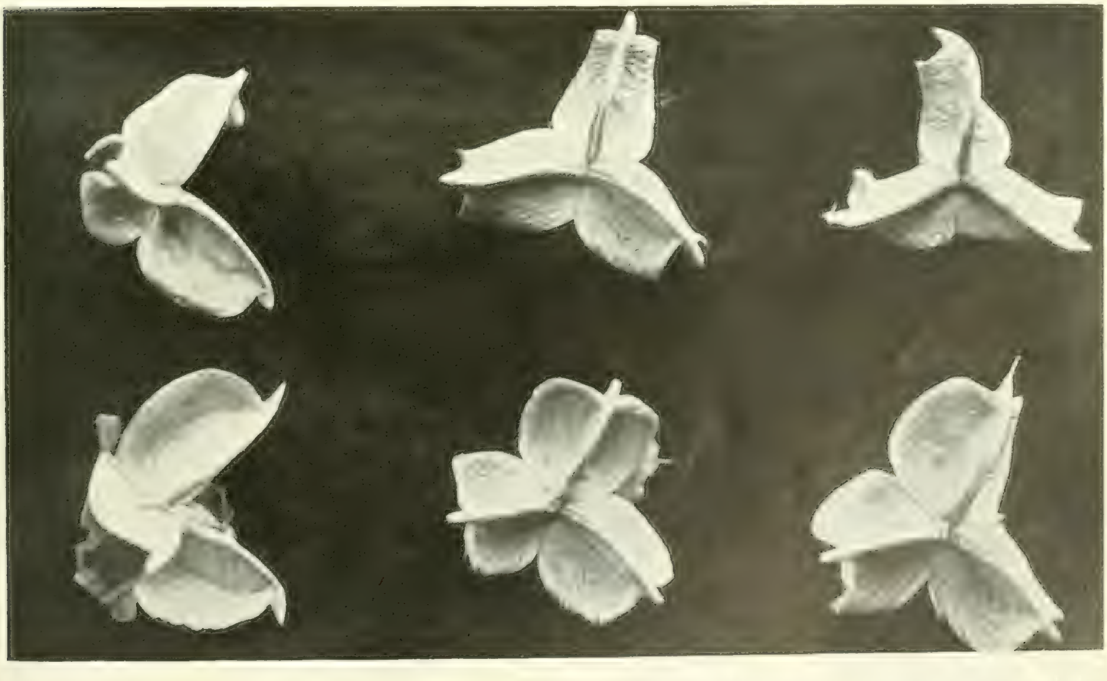
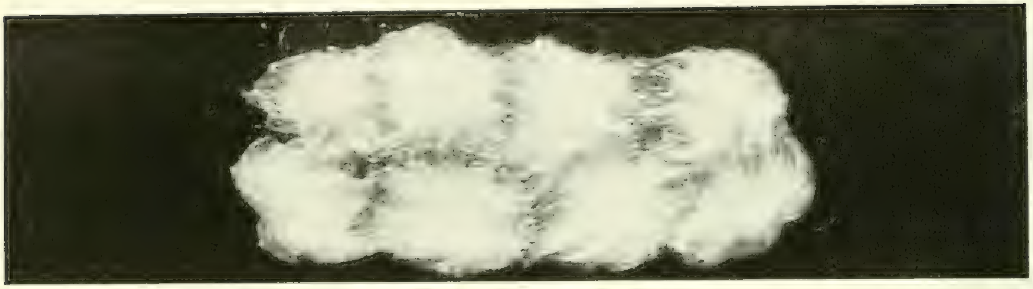
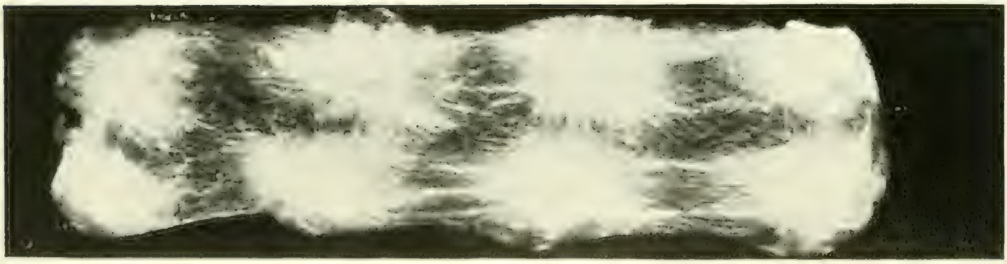


Fig. 2. *Upper row.* Surtee Broach Deshi. 1, side view, having the horizontal septa and the middle angle broad; 2, 3, horizontal views having the recurving on the sides.

Lower row. 1, side view, having the perpendicular septa forming the middle angle acute; 2, 3, horizontal views having no recurvature.





Above. Kapas from the cell of a boll of Goghari showing the length to which each seed with lint hairs can be drawn from the other without perfect separation. This is probably due to the shortness and roughness of the staple.

Below. Kapas from a cell of a boll of Broach Deshi showing the greater length to which each seed with lint hairs can be drawn from the other without complete separation. This is probably due to a long and silky staple.

of flowering and the character of the flowers are the same. All the types of bolls found among *Goghari* are also found among *Broach deshi* cottons (Plate V, fig. 2), and there is no evidence for the statement of Middleton that the bolls are globose and larger than those of *Broach deshi*. But as soon as the bolls open the characteristics of the variety appear. These are three in number.

1. The opening of the bolls is strikingly different in *Goghari* cotton from that of *Broach deshi*. In the latter cotton the edges of a cell of a boll recurve when fully open; in *Goghari* this never occurs. (Plate III, fig. 1.)

As a result, the angle between the septa in the shell of the completely opened boll is greater in the case of *Broach deshi* than in *Goghari*. (Plate III, fig. 2.)

2. The *kapas* in the two cases differs in the ease with which the seeds can be separated from one another. In *Goghari*, as has been already pointed out by Middleton, the lint hairs surrounding each seed separate readily from those of the adjoining seeds and the seeds do not, therefore, cling together by means of the lint hairs in the manner which is characteristic of *Broach deshi* cotton. This can be seen in Plate IV. The difference is probably due to the lint hairs in *Goghari* being shorter and thicker than in the other variety.

At the same time the lint adheres much more firmly to the seed than in *Broach deshi* cotton. This can be indicated, somewhat roughly, by the relative time taken to hand-gin *kapas* of the two types.

	Goghari		*Broach deshi*	
	Hours	Minutes	Hours	Minutes
Time taken to gin 1 lb. *kapas* ..	1	14	0	34
Time taken to obtain 1 lb. lint ..	2	43	1	40

3. The seed, after ginning, in *Goghari* cotton usually retains a large number of torn lint hairs, showing the force required to separate them from the seed. As a result most of the previous writers on the subject, including Middleton, have stated that the seed bears more fuzz than is found in the case of *Broach deshi* cotton. Precisely the opposite is really the case, and if the torn lint hairs are removed by forceps, it is easily seen that the *Goghari* seed really presents an almost clean darkish testa without fuzz. The difference can be seen clearly in Plate V, fig. 1.

These differences render it easy to distinguish in the case of any ripening plants, or in the case of any collection of *kapas* or cotton seed whether we have to do with *Goghari* or *Broach deshi* cotton, and enable the proportion of each in a mixture to be determined. In addition to these characters by which *Goghari* cotton can always be detected, there are certain general commercial differences which distinguish any lots of the two types of cotton which may be placed on the market. These are as under :—

1. The lint in *Goghari* cotton is shorter than in *Broach deshi*, and this is practically universally the case among all the strains of each kind that have been examined. The attached table and graph (p. 85) show the frequency of different lengths of staple in an average pure strain of each variety, the lint being taken from the middle of the seed.

	Goghari	*Broach deshi*
cm.	Percentage of cases	
1·5 — 1·6	1	..
1·6 — 1·7	10	..
1·7 — 1·8	6	..
1·8 — 1·9	8	1
1·9 — 2·0	22	1
2·0 — 2·1	20	2
2·1 — 2·2	22	4
2·2 — 2·3	10	6
2·3 — 2·4	1	15
2·4 — 2·5	..	16
2·5 — 2·6	..	17
2·6 — 2·7	..	21
2·7 — 2·8	..	8
2·8 — 2·9	..	8
2·9 — 3·0	..	1

Though, therefore, there may be seeds among a sample of *Broach deshi* cotton which bear lint hairs shorter than those found in *Goghari*, yet in practically every case the average staple is shorter in the latter than in the former, and so far no strain of *Goghari* has been evolved or selected which has an average staple as long as even the lower types of *Broach deshi* cotton.

2. The ginning percentage, or in other words the proportion of weight of lint to weight of *kapas*, is much higher in the case of *Goghari* cotton than in the case of *Broach deshi*. It is this quality which has caused the large extension of the growth of *Goghari* cotton, and we may illustrate the difference between the two types we are comparing by a table showing

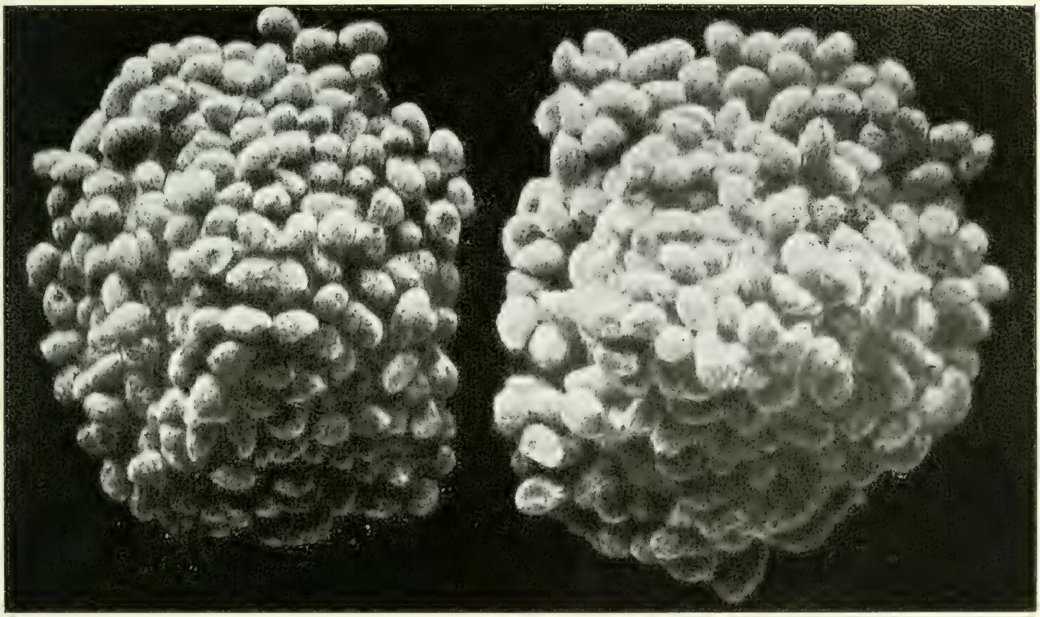


Fig. 1. ***Left side.*** Seed of Goghari almost naked (*i.e.*, without fuzz).
Right side. Seed of Broach Deshi so fuzzy as to present the velvety white surface all along.

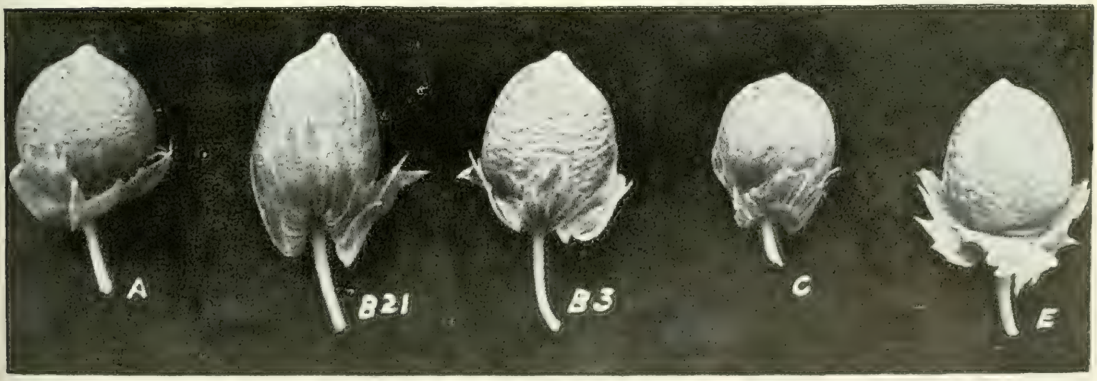


Fig. 2. A, Boll spherical in shape and bigger in size than C;
B 21, Boll distinctly tapering;
B 3, Boll tapering, surface rough (tall type);
C, Boll spherical but smaller than A;
E, Boll intermediate in shape between spherical and tapering.

the ginning percentage of a number of average samples of each kind purified and grown side by side.

	Ginning percentage of	
	Goghari	*Broach deshi*
(1)	44·5	37·7
(2)	41·6	36·8
(3)	42·3	38·4
(4)	41·8	35·4
(5)	43·8	32·3

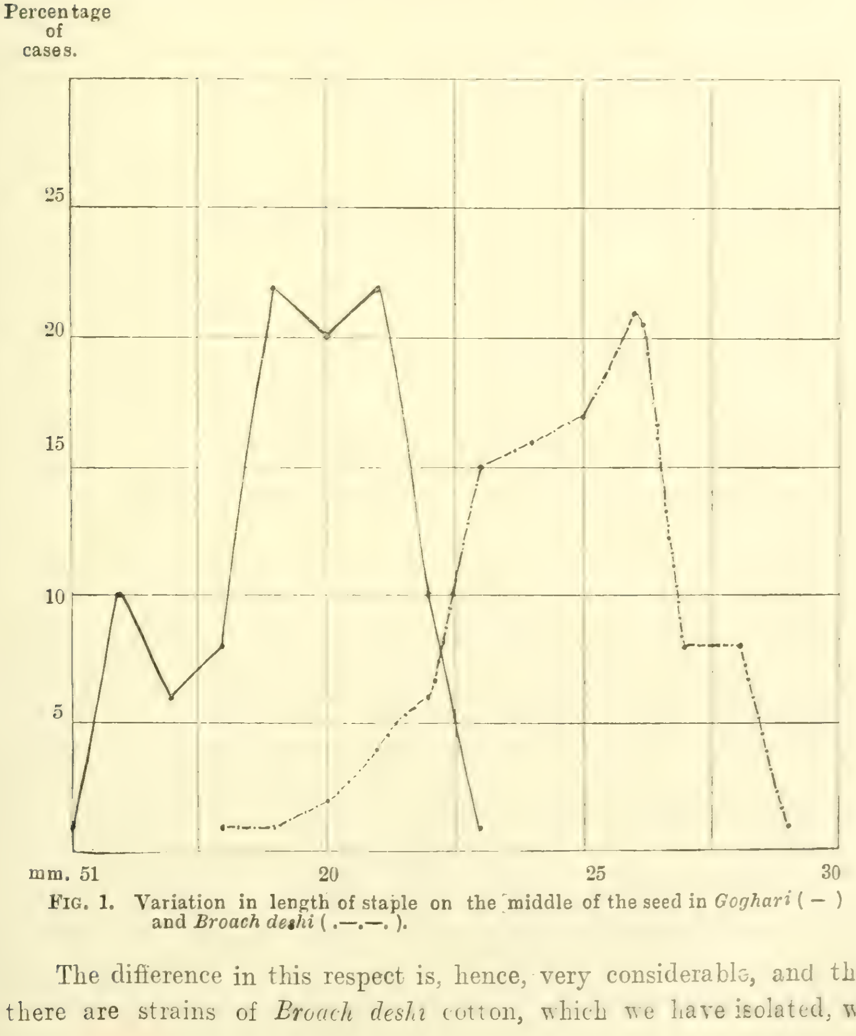


Fig. 1. Variation in length of staple on the middle of the seed in *Goghari* (—) and *Broach deshi* (.—.—.).

The difference in this respect is, hence, very considerable, and though there are strains of *Broach deshi* cotton, which we have isolated, with a ginning percentage higher than that of the poor strains of *Goghari*, yet the difference indicated by the above figures is maintained in the commercial lots of *kapas* in a remarkable manner, and is the basis for the high valuation of this *kapas* in the market.

Such are the differences between the two types of *herbaceum* cotton which are grown in Southern Gujarat, and the special characteristics of *Goghari* cotton which have given it a definite, if an undesirable, place in the market. Before passing on to consider the extent of its admixture with other cottons in Gujarat at present, we may notice the theories which can be put forward to account for its existence. The first theory on the subject is that of Middleton (*loc. cit.*) who considered that it is probably a cross between the *Broach deshi* cotton and the *Wagad* cotton of Northern Gujarat. The ground for this opinion is based on the fact that *Broach deshi* cotton bolls open wide and completely: those of *Wagad* only open slightly and have to be broken open to extract the cotton. In the case of *Goghari* various degrees of opening occur, some strains being almost as closed as *Wagad* when ripe, while others are intermediate between the two in this character. Against this opinion it may be noted, however, that the *Goghari* lint is whiter than either of its supposed parents, and, further, the ginning percentage is higher than either of *Wagad* or *Broach deshi*. These seem to make it at least doubtful, and it is, perhaps, more probable that *Goghari* really represents a developed and acclimatized *Wagad* type of cotton than a cross of the nature above indicated. In studying the various strains contained in *Wagad* cotton, we have, in fact, been able to isolate strains which are very similar to *Goghari* in manner of growth as well as in boll characters.

3. *Extent of admixture of* Goghari *with other cottons in Gujarat.*

On the strength of its high ginning percentage there has been a gradual tendency for *Goghari* cotton to spread throughout Gujarat until it is now found in almost every part of the province. Its ginning percentage is, however, its only advantage. The yield of *kapas* is certainly not greater than with other types of cotton equally suitable for almost every corner of the country, and the staple is recognized by all concerned to be inferior to that of the cottons which were formerly grown exclusively in these areas. But the difference in price resulting from the higher staple has not during the last twenty years been sufficient to prevent the temptation of a higher yield of lint on the *kapas* obtained leading to the gradual penetration of *Goghari* cotton throughout Gujarat.

In the year 1905, and again from 1909 to 1919, a number of samples of seed has been collected from ginning factories in many parts of Gujarat, and have been, after sowing and reaping of the crop obtained, used to determine the extent to which *Goghari* cotton was actually being grown in the various tracts. In the early years the samples were collected by the Mamlatdars or revenue sub-divisional officers; since 1913-14, the officers of the agricultural department have been responsible for obtaining them. The results of the examination of these samples can now be indicated.

Surat District. The reliable samples of seeds collected in the early years were too few to be of any value for the purpose in view, but since 1912-13 the following table indicates the amount of *Goghari* cotton contained in the samples of seed collected :—

Year	Number of samples examined	Average percentage of *Goghari*
1912–13	8	1·3
1913–14	15	1·0
1914–15	17	0·2
1915–16	30	0·6
1916–17	26	3·7
1917–18	18	0·9
1918–19	11	7·5

These figures, which owing to the limited number of samples examined must only be approximate, indicate that until recently the penetration of *Goghari* cotton into the Surat District has been only small. In 1916–17 for the first time it amounted on an average to nearly four per cent. and though in 1917-18 the figure obtained went down, it rose to an unprecedented height in 1918–19. The chief disquieting feature in the last year was the fact that all samples showed a mixture, and hence it was clear that *Goghari* cotton seed was penetrating everywhere, even in the areas where the highest staple strains of *Broach deshi* cotton had been previously grown. The result has been that the trade has become alarmed, and that an effort against the further invasion of *Goghari* types is being made by the combined action of the agricultural department in supplying pure seed, and of the various sections of the trade.

Broach District. The examination of samples from the Broach District has been more satisfactory and has given clear results showing the penetration of *Goghari* cotton. Here it must be remembered, we are in the centre of distribution, and though in 1905 the pure *Goghari* cotton was confined to one corner of the district, yet the ease with which it could be spread led to its rapid extension. The actual averages obtained were as under :—

Year	Number of samples examined	Average percentage of *Goghari*
1914–15	18	22·3
1915–16	19	24·2
1916–17	18	40·6
1917–18	24	50·7
1918–19	13	81·8

From these figures it is clear to what extent *Goghari* cotton has replaced the older type of *Broach deshi* of superior staple. This is partly due to the mixture of seed : partly to the actual replacement of the one variety by the other. In 1918–19, in almost a quarter of the cases the samples received were almost pure *Goghari* cotton seed, in the remainder the admixture varied from 65 to 88 per cent. of *Goghari* seed. There was no pure *Broach deshi* seed sample among them.

The same penetration of *Goghari* seed from Broach into Ahmedabad and Kaira is taking place as is occurring in Surat, but already it has proceeded much further. Viramgam and the surroundng tracts are little affected as yet but everywhere else the *Goghari* type is becoming increasingly grown from year to year The number of samples examined is, however, not sufficient to justify a quotation of them, but there is no doubt that the spread is taking place, a spread which is tending to ruin the reputation of Gujarat as an area for producing a staple cotton.

4. *Has hybridization occurred among the various types of Gujarat* herbaceum *cottons?*

With regard to the various types—*Wagad*, *Broach deshi* and *Goghari*—of Gujarat *herbaceum* cottons, which are growing together or in close proximity in so many parts of the province, two things may have occurred. Either they are growing side by side without appreciable mixture, or they have largely hybridized and so every form of cross intermediate between the types will be found. If the former be the case, then it will be easy to obtain each variety pure by simply selecting plants true to any type in the field : if, on the other hand, the latter be the condition, it will be difficult by field selection directly to get plants which will breed true of any of the varieties described.

The extent to which hybridization of cotton takes place generally has been a matter of considerable controversy. Without going into the older literature on the subject, we may call attention to Gammie's opinion in 1903.[1] He states as follows :—

"It is customary among botanists to assume that the numerous forms of cotton plants have become inextricably complicated and difficult to understand and distinguish through hybridization. It appears to the writer that the true solution of the problem of classification will be found to lie in the fact that, in the Indian form, these so-called species and hybrids are merely cultivated races evolved from an unknown prototype." A little later (1905) Gammie[2] was more definite, and stated that in his opinion the numerous forms occurring in every species of Indian cottons were not to be explained through hybridization, in that Indian cottons are normally self-fertilized. "A large number of varieties," he said, "procured from almost every part of the country have been grown in contiguous lines without hybridizing. Emasculated flowers allowed to remain uncovered usually drop off unfertilized. In the few cases where pollen was carried to the stigmas by insects, bolls were not subsequently developed."

This very clear opinion that crossing among Indian cottons is of rare occurrence, and, when it occurs, is of little practical importance, is not shared by other workers on the subject. Watt[3] writes as though he considered that cross-fertilization was frequent and that many Indian types have risen through such natural hybridization. Leake[4] after a very careful series of observations came to the conclusion that in Indian cottons "cross-fertilization takes place to a considerable extent, though the greater portion of this is limited to neighbouring plants." He says, further, that cottons which flower by the end of the rainy season are more liable to cross-fertilization than others.

It may well be, however, that in different species of cotton, the tendency towards hybridization will be very different. Thus, for instance, cross-fertilization would be very difficult in *Gossypium arboreum* with its short style, while in the various types of *Gossypium neglectum*, where the length of style gives much more opportunity for foreign pollen to be received, it might easily be frequent. The forms of *Gossypium herbaceum* occupy an intermediate position, and none of the workers above quoted have made careful and detailed observations of the incidence of crossing with this species.

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[1] Note on the Classification of Indian Cottons, Calcutta, 1903.

[2] The Indian Cottons, Calcutta, 1905.

[3] Wild and Cultivated Plants of the World, London, 1907.

[4] *Mem. Dept. Agri. India, Botanical Series,* IV, no. 3.

We have, however, now the recent work of Kottur[1] on this point. He worked with various types chiefly of *herbaceum* cottons, and concluded that "all the Indian varieties cross easily and the amount of natural crossing is considerable (up to 6 per cent.) when various varieties are grown in adjoining fields." Beyond this opinion there is no evidence, so far as we are aware, of the degree to which cross-fertilization occurs among *herbaceum* cottons, or of the extent to which the plants now grown are unfixed hybrids of the various varieties in cultivation.

That cross-fertilization does actually occur in the *Goghari* type of *herbaceum* cotton is clear from the following experiment :—

Strain No. C 8 *Goghari.* This is a pure line cultivated without variation for several seasons. In 1918–19 the seeds produced by two separate plants of 1917-18 were sown, and variations in the amount of *kapas* per boll and in the ginning percentage of the *kapas* were noted which could only have resulted from crossing. The rows were planted at least six feet from any other type. The actual figures obtained were as under :—

Number of bolls per pound of *kapas*	No. 1–348 No. 2–407
Ginning percentage	No. 1–44·2 No. 2–46·6

Degree to which cross-fertilization occurs. We have started our work by isolating pure line cultures of *Goghari* cotton which have maintained certain of their characters for at least two generations. The seeds produced in open field cultures in the second generation (the plants being grown no less than six feet by three feet apart) have then been grown, and the proportion of the plants which have varied in the next generation in the character studied has been determined. The only source from which such variations could arise was cross-fertilization from the plants in the field. The following cases may be quoted :—

1. *Strain No.* B21 *Goghari.* The character studied was the size and shape of the boll. This was absolutely constant in 1916–17 and 1917–18. On being grown in open culture in 1918–19, it showed 2·1 per cent. of the plants bearing bolls of a different character. Again a plant bearing bolls of the original shape and size in 1918–19 gave 2·85 per cent. of the plants with varying bolls in 1919–20.

2. *Strain No.* C22 *Goghari.* The same character was studied as in the last case, and the boll characters of the strain were constant in 1917–18 and 1918–19. In 1919–20 this showed plants with varying bolls to the extent of 1·1 per cent.

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[1] *Mem. Dept. Agri. India, Botanical Series,* X, no. 6, 1920.

3. *Strain No.* B3 *Goghari.* The boll characters were again studied and after being constant in 1916-17 and 1917-18 these showed 1 per cent. of the plants in 1919–20 with varying bolls.

Judged therefore by this one character, it would suggest that under the conditions of the experiment, in which the nearest differing plants of other strains would be six feet or more away, the amount of crossing would, in *Goghari* cottons be between 1·0 and 2·8 per cent.

That the plants at present grown are unfixed hybrids of the varieties in cultivation is still more clear. Seed of two types of *Goghari* cotton (Jambusar *Goghari* and Varnama *Goghari*) were obtained and sown. From the crop obtained, all plants were eliminated which showed any character other than those associated with *Goghari* cotton. Seed was produced from the remainder and this was again sown. Instead of producing pure *Gohgari* plants, however, the latter showed a higher percentage of admixture with those of other types than did the original cotton. The actual figures in both cases are as under :—

Year	Jambusar *Goghari* Percentage of admixture of *Broach deshi*	Varnama *Goghari* Percentage of admixture of *Broach deshi*
First year (1913–14)	7·25	9·50
Second year (1914–15)	14·00	10·00

It is clear, therefore, that the plants grown were "splitting" as to one or more of the characters associated with *Goghari* cotton.

A similar test was made with a sample of cotton seed, reputed to be *Broach deshi*, obtained at Broach. The seed was grown as before, and all the plants which did not conform to the *Broach deshi* type were eliminated, and the seed produced from the remainder was sown in the following generation. In this case the series was continued for four years ; only in the fourth year had the *Goghari* type been entirely got rid of, as the following figures show :—

	Broach deshi Percentage of of admixture with other types
First year (1913–14)	82·3
Second year (1914–15)	14·8
Third year (1915–16)	2·5
Fourth year (1916–17)	0·0

A third test may be quoted. In seeking to develop pure strains of *Goghari* cotton, we commenced by selecting in the field, with great care, plants which completely conformed to the *Goghari* type. The seeds from these plants were sown, and the plants from their produce were examined. The following table shows the percentage of these which conformed to the *Goghari* type in 1915–16 :—

Strain	per cent.
A ..	.. 43·9
B ..	.. 40·3
C ..	.. 45·1

Allowing that a limited amount (not more than 3 per cent.) of cross-fertilization may have taken place in the field, this would be totally insufficient to account for such a large proportion of non-*Goghari* plants in the offspring of those selected.

These results, therefore, seem to show conclusively in the *herbaceum* cottons of Gujarat, or at any rate in the *Broach deshi* and *Goghari* types, the following points :—

(1) That cross-fertilization of the different types of *herbaceum* cottons does take place.

(2) That this cross-fertilization takes place normally to the extent of 1 to 2·85 per cent. and perhaps more.

(3) That the cotton plants in cultivation are very largely composed of hybrids between the various types described, and, hence, ordinary selection on the basis of the characters of the produce of a particular plant will not yield a constant type either of plant or produce.

5. *What characters are hereditary in* Goghari *cotton ?*

In considering which of the characters associated with *Goghari* cotton are hereditary, we have studied the following. We will first state what we have found with regard to each of them and then describe the data on which these conclusions are based.

Boll characters.

(1) The shape of the boll (spherical, tapering, etc.) is hereditary.

(2) The size of the boll, at any rate so far as the spherical type of boll is concerned, is hereditary.

(3) The quantity of *kapas* per boll is hereditary.

Plant Characters.

(1) The proportion of bolls borne on primary fruiting branches is hereditary.

Seed and lint characters.

(1) The ginning percentage of the *kapas* is hereditary, but there are variations from season to season due to reasons other than seed weight.

(2) The seed weight is hereditary.

The evidence on which these statements are based is as follows :—

1. *The shape of the boll is hereditary.*[1] In ordinary *Goghari* cotton, as grown, there are very great variations in the type of boll. Some of these variations are shown in Plate V, fig. 2, which represents the character of the bolls in a number of strains (pure) which we have isolated and each of which is described in the next section of the present paper. These may be indicated as under :—

A. Spherical in shape and large.
B. (1) Long and tapering with smooth surface.
 (2) Tapering with rough surface.
C. Spherical, but small.
E. Intermediate in type between A and B.

The original types, from which these strains have been developed, were selected in 1914–15, on the basis of these very boll characters. On growing, however, they were found each to yield plants with bolls of the most varying kinds, more than 55 per cent. in the case of types A, B, and C being rejected in the first year's crop. By careful selection, however, plants have been obtained which breed entirely true to this character. In the strains with boll characters represented by A, plants had been evolved by 1918–19 whose progeny gave an absolutely uniform series of spherical bolls, breeding true year after year. Similarly in strains with the characters of B and C, the same stage was reached in 1916–17, while in those with characters of E, the plants bred true as to the type of boll in 1917–18.

2. *The size of the boll and the quantity of* kapas *per boll are hereditary.* In an ordinary collection of bolls of *Goghari* cotton the variation in size is very great, even in the same season. Some idea of this can be given by figures for a large number of bolls from our own plots, which are of course more uniform than the types in ordinary fields. The size will perhaps be best indicated by the number of bolls required to give one pound of *kapas.* This varied in two different years as follows :—

1917–18. 181 to 247 or a variation from the mean of 15·4 per cent.

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[1] Balls. "The Cotton Plant in Egypt," London, 1912.

1918–19. 214 to 289 or a variation from the mean of 14·9 per cent.

Several strains have been isolated in which the number of bolls required to yield one pound of *kapas* is almost constant in any one season.

Thus the progeny of different plants of one pure line gave the following numbers in certain cases.

(1) 217 and 214 from a parent giving 220 bolls per pound of *kapas*.

(2) 186, 193, 208 and 210 bolls per pound of *kapas* (parent not recorded).

(3) 249 and 241 from a parent giving 241 bolls per pound of *kapas*.

(4) 273 and 288 bolls per pound of *kapas*.

In these cases the variation from the mean among the progeny is only 0·7, 6·5, 1·6 and 2·6 per cent. respectively, and in the cases where the character of the parent was recorded, the variation is 2·8 and 3·3 per cent., though the parent and the progeny were grown in different seasons.

3. *The proportion of bolls borne on primary fruiting branches is hereditary.* It is well known that in all *herbaceum* cottons there are three positions in the plant in which bolls may be borne. They may arise on secondary or tertiary branches, borne either on monopodia near the base or on vegetative axillary shoots growing in the upper part of the plant ; and they may occur on primary fruiting branches arising directly from the main stem. In most species of cotton, the last kind of bearing is almost exclusively found : in *herbaceum* cottons, the former kind has a very important share in the number of bolls and hence in the quantity of *kapas* produced. The proportion of the total number of bolls borne on the primary fruiting branches seems, however, to be constant for a pure strain in *Goghari* cotton.

The following table gives figures showing how the progeny of selected plants of each strain are constant in this factor.

Table showing percentage of bolls borne on primary fruiting branches.

	Percentage	
Strain A26	1918–19	1919–20
Progeny of plant 1	30·6	..
Progeny of plant 2	30·3	..
Strain B3		
Progeny of plant 1	36·8	
Progeny of plant 2	35·0	..
Strain B21		
Progeny of plant 1	21·6	..
Progeny of plant 2	22·5	..
Strain C22		
Progeny of plant 1	33·3	..
Progeny of plant 2	29·0	..
Progeny of plant 3	29·0	..
Progeny of plant 4	28·8	..

Strain E5	Percentage	
	1918–19	1919–20
Progeny of plant 1	32·5	32·4
Progeny of plant 2	36·0	33·8

The variation between the progeny of different plants is so small, and, moreover, the difference in the last quoted case is so slight from year to year, that it justifies us in concluding that we are here dealing with a hereditary factor. This matter, however, requires further study.

4. *The ginning percentage of* kapas *is hereditary.* Seeing that in *Goghari* cotton it is the high ginning percentage which has raised the variety to its present importance, it is a matter of great interest to ascertain how far this quality is one which is innate in any particular strain, and hence whether strains can be isolated which possess this very valuable character in an exceptional degree, and which will breed true. Our observations show that such strains can be isolated, that plants derived from similarly bred parents in pure line will have similar ginning percentage, and that the ginning percentage of the progeny, in pure strains, will only vary within defined limits from that of the parents.

We will give the figures obtained for the ginning percentage in several pure strains and for a series of years.

		Ginning percentage
Strain A26	1916–17	44·6
	1917–18	42·7
	1918–19	45·7, 45·4 and 46·6
	1919–20	42·5
Strain B3	1916–17	42·6
	1917–18	42·7, 42·8, 42·5, and 43·8
	1918–19	45·8 and 45·1
	1919–20	46·9
Strain B21	1916–17	45·4
	1917–18	42·6
	1918–19	45·5 and 44·6
	1919–20	44·8
Strain C22	1916–17	46·1
	1917–18	42·0, 42·5, 42·4 and 42·9
	1918–19	45·7 and 45·8
	1919–20	47·6
Strain E5	1916–17	46·4
	1917–18	46·7, 46·1 and 46·6
	1918–19	49·8 and 48·8
	1919–20	51·5

The variation between the progeny of different plants of the same strain grown in the same year is very small indeed. Environmental factors appear to have a very large effect on the ginning percentage in any one year as compared with any others, and they seem, moreover, to have a somewhat different effect in different strains (*e.g.*, A26 and B3). But there are strains which consistently give a very high ginning percentage like E5, and which may have great importance from a breeding point of view on this account.

A critical examination of these figures, however, suggests that the ginning percentage is itself a complex, being dependent on the weight both of the seeds and of the lint. A rise in the ginning percentage might in fact be brought about either by an increase in the lint weight or by a decrease in the seed weight, and hence a better figure to measure the proportion of lint in a well-developed boll would be to compare the weight of lint with the number of seeds and not with their weight. That is to say, we should use a figure which compares the weight of lint per 100 seeds. This figure has been already used by the writers in Egypt under the name "Lint-index" and its value in the cases quoted in the last table is as follows :—

Lint-index (weight of lint in grammes per 100 *seeds*).

		Grm.
Strain A26 ..	.. 1916–17	4·31
	1917–18	4·29
	1918–19	4·80, 4·91 and 5·04
	1919–20	4·82
Strain B3 ..	.. 1916–17	4·11
	1917–18	4·04, 4·13, 4·05 and 4·25
	1918–19	4·66 and 5·05
	1919–20	5·15
Strain B21 ..	.. 1916–17	4·01
	1917–18	3·98
	1918–19	4·30 and 4·30
	1919–20	4·60
Strain C22 ..	.. 1916–17	4·33
	1917–18	3·73, 3·93, 3·92 and 3·95
	1918–19	4·29 and 4·37
	1919–20	4·80
Strain E5 ..	.. 1916–17	4·49
	1917–18	4·75, 4·69 and 4·84
	1918–19	5·50 and 4·96
	1919–20	5·73

The constancy of the lint-index is greater than that of the ginning percentage as is well illustrated in the case of Strain A26, 1919–20, as against 1918–19, and hence it appears to be a better factor to use in considering the relationship of the lint and the seed.

It is a general belief among cotton merchants that variation in the ginning percentage in one type of cotton is due simply to variation in the seed weight. Our results show, however, that this is not the case, and that in any of our pure strains the variation in the seed weight is only one of the factors which causes changes in the ginning percentage. The following table shows the ginning percentage in several years, and also the number of seeds per gramme. There is obviously little or no correlation between the two sets of figures.

Strain	1916–17		1917–18		1918–19		1919–20	
	Ginning percentage	Seeds per gramme	Ginning per-centage	Seeds per gramme	Ginning per-centage	Seeds per-gramme	Ginning per centage	Seeds per gramme
A26	44·6	18·6	42·7	17·3	45·9	17·2	42·5	15·3
B3	42·6	18·0	42·9	18·3	45·4	17·2	46·9	17·2
E5	46·4	19·3	46·5	18·4	49·3	18·5	51·5	18·5

5. *The seed weight is hereditary.* This has already been recognized by Balls[1] for Egyptian cotton, and it is equally the case in the *Goghari* variety of *Gossypium herbaceum.* The following figures for the same strains which we have considered under the last heading make this clear in the present case :—

		Number of seeds per 10 grm.
Strain A26 ..	1916–17 ..	186
	1917–18	173
	1918–19	175, 169 and 173
	1919–20	153
Strain B3 ..	1916–17 ..	180
	1917–18	184, 181, 182 and 183
	1918–19	179 and 163
	1919–20	171
Strain B21 ..	1916–17 ..	207
	1917–18	186
	1918–19	194 and 186
	1919–20	176
Strain C22 ..	1916–17 ..	196
	1917–18	194, 188, 187 and 190
	1918–19	196 and 193
	1919–20	189
Strain E5 ..	1916–17 ..	193
	1917–18	184, 185 and 180
	1918–19	180 and 192
	1919–20	185

These figures indicate that the progeny of different plants of the same strain grown in the same year give seed whose weight varies very slightly. It also shows that despite considerable variations from year to year, a heavy-seeded variety remains relatively heavy-seeded however the environmental factors may vary.

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[1] Balls. "The Cotton Plant in Egypt," London, 1912, page 167.

Closely connected with this study of some of the characters of *Goghari* cotton which we have proved to be hereditary, we may note the results of our inquiry into the correlation between the shape and size of the bolls in *Goghari* cotton and the ginning percentage. In commencing selection work on this cotton in 1914–15, we relied on this character of the bolls as being a favourable basis for selection as a result of statements by several authorities that boll characters were intimately associated with length of fibre. Thus O. F. Cook[1] states definitely that there is a correlation between the length of the boll and the length of the fibre. Kearney[2] also, in his study of breeding in Egyptian cotton, ventures the statement that " the size of the bolls must be considered, ...because this character is intimately associated with length of fibre." He does not give any evidence for this, and we cannot find the evidence on which it was based. Main[3] held the same opinion, and stated that in 1911–12 he made the " interesting observation that a correlation exists in the indigenous cottons between the ginning percentage on the one hand and the shape of the bolls on the other." A broad-shaped boll was found to be associated with a higher ginning percentage in the *kapas*. He, however, does not give the evidence on which he based this statement.

After six years' work on the subject we have to say that we have failed to find the correlation expected ; although all our selections were originally made on the basis of the size and shape of the bolls, yet the pure strains we have developed from them have not given a ginning percentage which varies in any sense according to their origin. The following table shows this :—

Strain	Boll characters	Ginning percentage			
		1916–17	1917–18	1918–19	1919–20
A26	Spherical and large	44·6	42·7	45·9	42·5
B3	Tapering and large	42·6	42·9	45·4	46·9
B21	Tapering and medium size	45·4	42·6	45·5	44·8
C22	Spherical and small	46·1	42·5	45·7	47·6

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[1] *Bulletin* 159, *U. S. Dept. Agri. Bur. Plant Industry*, p. 45.

[2] *Bulletin* 200, *U. S. Dept. Agri. Bur. Plant Industry*, 1910, p. 11.

[3] *Annual Report Surat Experimental Station*, 1911-12 (Bombay, 1912).

The supposed connection between the shape and size of the bolls obviously does not exist. The highest ginning percentage in the series has been given by a plant with small bolls which were spherical, and the lowest by one which had large and spherical bolls.

Another correlation which has been announced to occur is that between the size of seed and yield which plants produced from it might be expected to give. This was stated by Cook[1] in 1908, where he describes the advantages of light seeds, heavy seeds and large-seeded varieties. On the strength of experiments by Shoemaker on " Triumph " cotton, he connected the increase in yield rather with the development of large seeds. That there is no necessary connection between heaviness in seed and the yield of a variety in *Goghari* cotton is indicated by the following table. A26 was a heavy-seeded strain ; C22 on the other hand was a light-seeded strain, the seeds being 5 per cent., 7·8 per cent., 10 per cent. and 19 per cent. lighter than those of A26 in the four years 1916–17, 1917–18, 1918–19 and 1919–20 respectively. The table indicates the yield per plant in these four years.

Yield of kapas *per plant.*

Strain	1916–17 Grammes	1917–18 Grammes	1918–19 Grammes	1919–20 Grammes
A26 (heavy-seeded)	2·90	7·87	5·38	7·91
C22 (light-seeded)	4·44	4·94	6·30	7·88

The yield and weight of seed, therefore, seem to depend on altogether different factors, and no connection seems to exist between them whatsoever.

One more point in correlation arises. It has been suggested by Gammie[2], though he gives no evidence whatever in favour of his assertion, that a tall shortly branched form of the cotton plant "appears to be the more productive in all species of Indian cottons." A statement which might be interpreted to mean the same was issued by Kottur[3] in 1917, but he has since made it clear that the tallness of the plant has, in his opinion, nothing to do with the yield, but rather the proportion between the different types of branches (fruiting) on the plants. In view of Gammie's statement, however, it was necessary to ascertain whether there was any connection between tallness and yield, as we have again and again, as a result of it, been recommended to carry on selection on the basis of the tallness of the plants used for the purpose. We have separated two strains: one (B3) which was the tallest of all in the sense that the main stem tended to develop to a great extent, and the other (E 5) which did not have this faculty. The yield in *kapas* of each of these strains per acre grown side by side, in a series of years, was as follows :—

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[1] *U. S. Dept. Agr. Bur. Plant Industry, Circular* 11, 1908.

[2] *Report of the Imperial Cotton Specialist,* 1916–17, p. 3.

[3] *Bulletin no.* 84, *Dept. of Agri. Bombay,* 1917.

Year	B3 (Tall strain)	E5 (Strain not tall)
	lb.	lb.
1917–18	157	164
1918–19	253	318
1919–20	332	510

It is obvious that in these two strains, both isolated from *Goghari*, there is no correlation between tallness and yield. It is difficult to understand how anyone ever supposed that such correlation was likely to exist.

6. *Description of certain pure line strains of* Goghari *cotton.*

From the discussion of *Goghari* cotton so far made, it has become clear that what goes under that name really consists of a series of strains, all of which possess the varietal features described on page 83, but which differ from one another by characters which are very important commercially, and of which some, at least, are hereditary and breed true. These strains, however, are not merely mixed ; they have crossed with one another to an enormous extent, and few, if any, of a pure character now exist in the whole province. Any attempt to improve or even to fix a standard type for *Goghari* cotton must be commenced, evidently, by the development of such pure strains breeding true, which could be the basis of establishing types or of making crosses with other strains of *Goghari* or with other varieties of cotton.

We have isolated five strains of *Goghari* cotton, and we may now give a description of each of these as it has behaved in pure line culture since 1916–17 or 1917–18.

Strain A26.

The first of these selected strains, which has been termed A26, is derived from a selection originally made on the basis of the shape and the size of the boll. The manner of making the selection, in the first instance, was to pick out in an ordinary field of *Goghari* cotton, 188 plants which had round, spherical and large bolls. The progeny of each of these plants was sown separately in a row, the rows being six feet apart ; from the resulting plants all of which did not produce the same characters in the bolls for which they had been selected were eliminated leaving those which still gave the characters desired. Since that time unit selection among the plants so left has been carried on, with the result that since 1918–19 we have a type which has bred absolutely true, and which represents a pure line with the following characters.

The plant of the strain is of a bushy character, and bears a number of monopodia varying from one to eight, the most frequent being four to five. The leaves and formation of the plant are similar to what is usually found in *Goghari* plants. The special characteristics are :—

(1) The bolls are spherical and large, with a very marked point at the tip. The bolls open well on the plant, and are fairly uniform in character. The average weight of *kapas* per boll is 2·12 grm.

(2) The *kapas* gave a ginning percentage of 45·9 in 1918–19 and 42·5 in 1919–20. The lint-index (that is to say, the weight of lint in grammes per 100 seeds) was 4·93 in 1918–19 and 4·82 in 1919–20.

(3) The seed is rather larger than the average for *Goghari* cotton, and 100 seeds weighed in 1918–19, 5·81 grammes. In 1919–20, 100 seeds weighed 6·53 grammes.

(4) The lint varies in length of staple according to the part of the seed from which it is derived. In 1920 the average length was as follows :—

	Centimetres
Lint on tip of seed	1·72
Lint on middle of seed	2·01
Lint at base of seed	1·91

The variation in the length of the staple of the lint at the various parts of the seed is : (1) at the tip 8·5 per cent. below the mean ; (2) at the middle 7 per cent. above the mean ; (3) at the base 1·6 per cent. above the mean. The attached frequency curve shows the extent to which the staple of the lint from the middle of the seed varies in a lot of seed of the pure strain.

The comparative constancy of the staple is shown by the following figures, all taken in the middle of the seed.

Number of measurements made	100
Staple of 1·7 centimetres	1
Do. 1·8 Do.	17
Do. 1·9 Do.	14
Do. 2·0 Do.	28
Do. 2·1 Do.	20
Do. 2·2 Do.	13
Do. 2·3 Do.	7

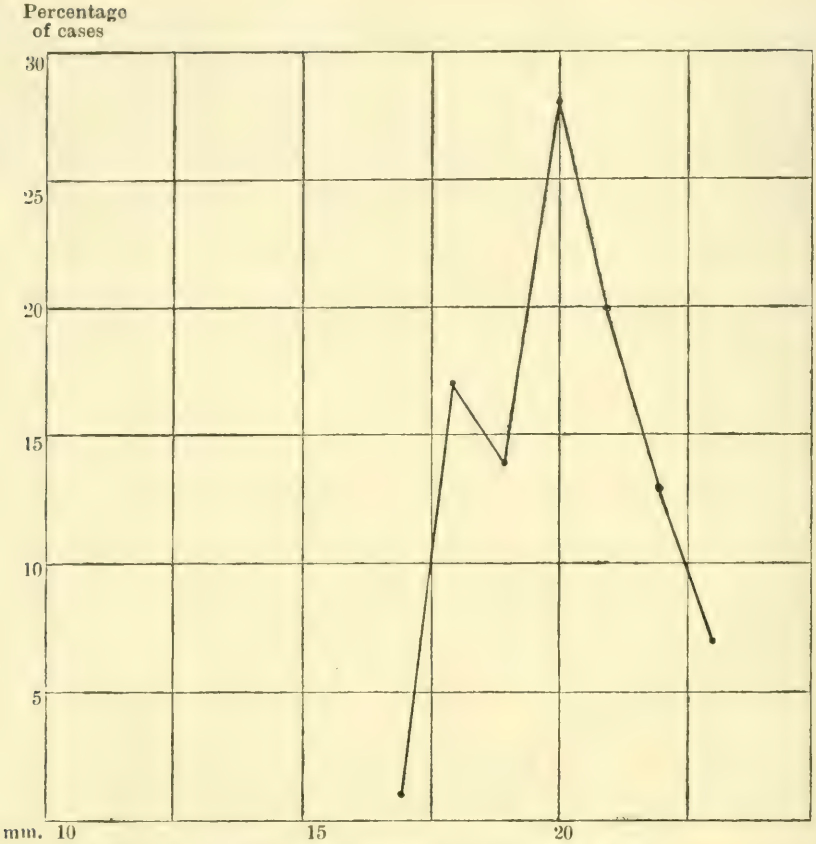


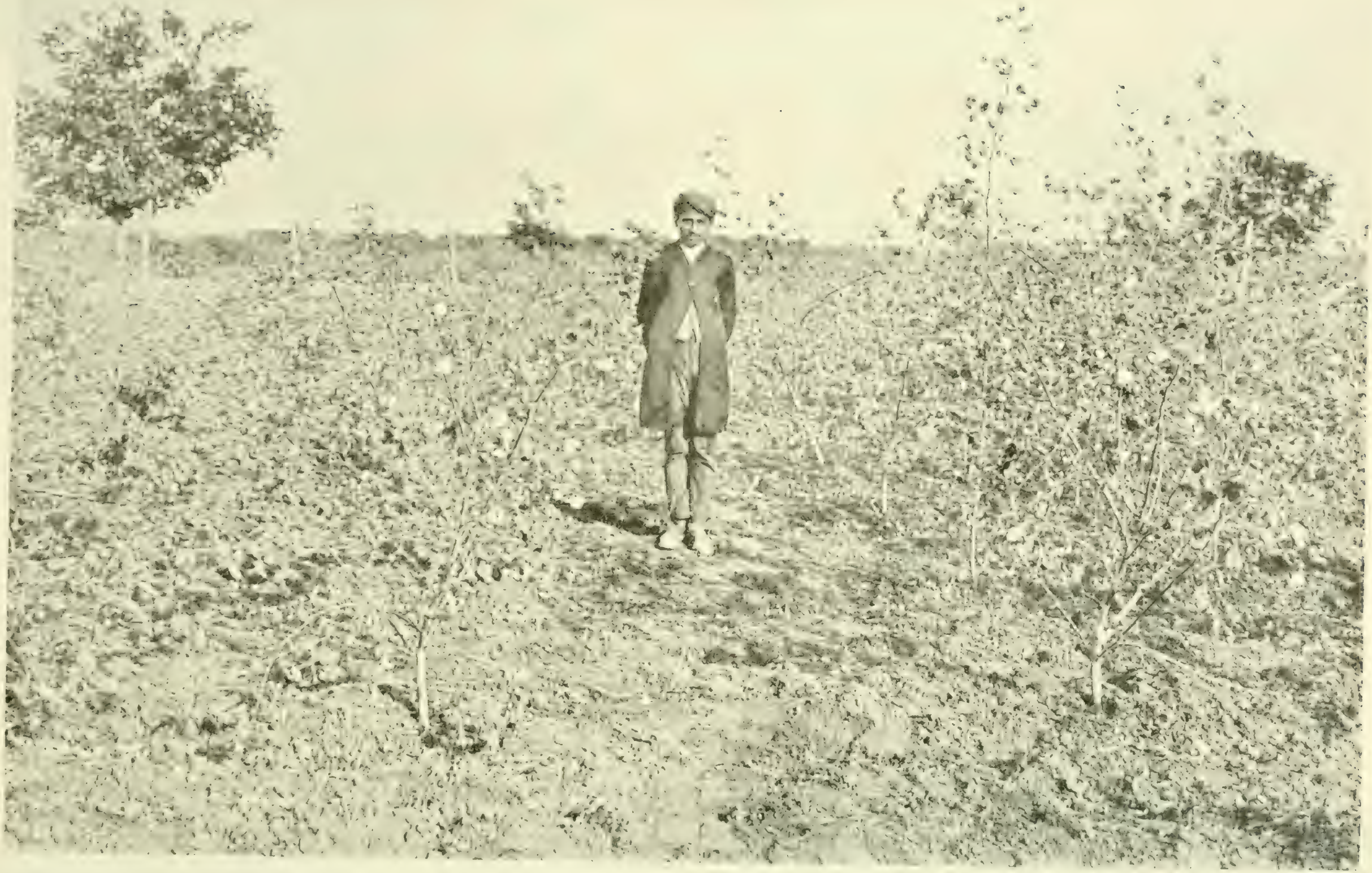
Fig. 2. Variation in length of staple on the middle of the seed in *Goghari* A26.

The lint from this strain of *Goghari* cotton has been very kindly examined by Messrs. Tata & Sons, Bombay, both in 1918–19 and 1919–20. The following are their valuations :—

Year	Value of lint per *candy* of 784 lb.	
	Fine Broach deshi	A26
	Rs.	Rs.
1918–19	600	450
1919–20	500	300

Such are the characters of this, the strain which perhaps most nearly approaches the typical *Goghari* cotton as grown in the country. It is retained

PLATE



Right side. Goghari B 3, having a tall habit of growth. Where the plants are pruned off, even the axillary vegetative branches have grown tall.

Left side. Goghari E, having no such tall habit.

in our collection not on account of superiority of either staple or ginning percentage but because it is an all-round good yielding cotton. Its ginning percentage is slightly above the average, while the staple represents about the mean for *Goghari* cotton.

Strain B3.

In the same year as the strain previously described was first selected, plants were picked out which had large and tapering bolls, for it was supposed at that time that a large boll means a cotton with a high ginning percentage and a tapering one would be likely to give a higher staple lint; unit selection was continued on the same basis in succeeding years, and a pure strain with the above boll characters breeding true was obtained in 1916–17. It was then discovered that the strain obtained had another character, namely, that the main stem was inclined to develop to an exceptional extent, and hence to give a tall habit to the plants.

We have, hence, a plant which while giving about the same number of monopodia as the strain previously described (the most frequent number being 5) and which hence is bushy in character, at the same time grows tall. The habit of the plant is well shown in Plate VI when it is compared with a strain (E5) later to be described. The tall character is so far a special feature of the strain that if the main stem is pruned, the axillary vegetative branches grow vertically and still give a plant a tall appearance In other respects the plant is typical *Goghari* in character.

The flowering of this strain of cotton was observed in 1918-19, when the succession of flowers in twelve plants was noted as follows :—

Number of flowers	from October	11 to 17 ..	142
Do.	Do.	18 to 24 ..	145
Do.	Do.	25 to 31 ..	193
Do.	from November	5 to 10 ..	148

A gap occurred between October 31st and November 5th, but these figures nevertheless show that the flowering is steady for over four weeks, rising to the greatest frequency in the latter part of the period. After the date above given rain occurred and flowering stopped.

The special characters of the produce in the strain of cotton are as follows :—

(1) The bolls are tapering, studded with dark dots on the surface which is rough. The bolls open as in a typical *Goghari* plant ; the weight of *kapas* per boll was :—

	Grm.
(*a*) in 1917–18 ..	2·27
(*b*) in 1918–19 ..	1·70

(2) The *kapas* gave a ginning percentage and lint-index as follows :—

Year	Ginning percentage	Lint-index
1916–17	42·6	4·06
1917–18	42·9	4·11
1918–19	45·4	4·85
1919–20	46·9	5·15

These figures show a tendency, under the conditions of the last two years, for both the ginning percentage and the lint-index to increase.

(3) The seed was about the average size and 100 seeds weighed as follows :—

Year	Weight of 100 seeds grm.
1916–17	5·55
1917–18	5·47
1918–19	5·85
1919–20	5·84

(4) The lint gave the following average measurements on the different parts of the seeds in 1920 :—

	Centimetres
Lint on tip of seed	1·63
Lint on middle of seed ..	1·94
Lint on base of seed	1·74

The variation from the mean (*a*) at the tip was 7·9 per cent. below, (*b*) at the middle 9·6 per cent. above, and (*c*) at the base 1·7 per cent. below.

The lint on the middle of the seed varied as follows, as determined from 100 measurements made on seeds :—

Number of measurements made ..		.. ..	00
Staple of	1·5	centimetres	1
Do.	1·6	Do.	10
Do.	1·7	Do.	6
Do.	1·8	Do.	8
Do.	1·9	Do.	22
Do.	2·0	Do.	20
Do.	2·1	Do.	22
Do.	2·2	Do.	10
Do.	2·3	Do.	1

The staple in this case is, therefore, not only shorter than with A26, but is also more uneven. The variation is illustrated in Fig. 3 below.

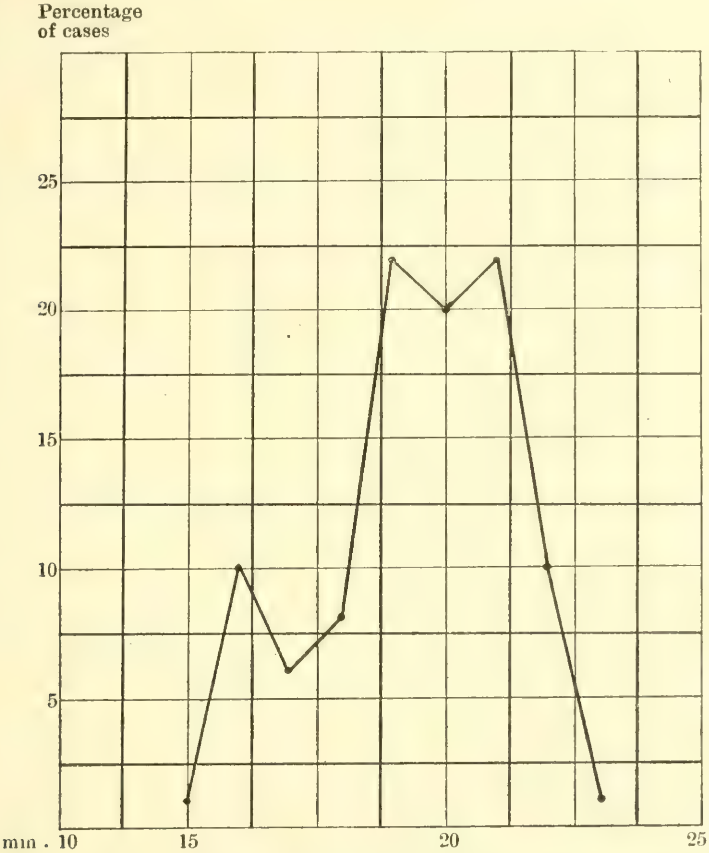


FIG. 3. Variation in length of staple on the middle of the seed in *Goghari* B3.

The lint was examined by Messrs. Tata & Sons, Bombay, in each of the years when it was grown, with the following results :—

Year	VALUE OF LINT PER *candy* OF 784 lb.		
	Fine Broach deshi.	B3	A26
	Rs.	Rs.	Rs.
1916–17	500	418	..
1917–18	950	800	..
1918–19	600	520	450

The strain just described possesses few characters which give it value. It is a low yielder, and its lint is not only short but is also uneven as in other strains of *Goghari* cotton. It is maintained simply because of its tall habit of growth, which may later cause it to be useful for crossing. As it stands, it is only valuable as showing the low characters of certain of the pure strains in *Goghari* cotton.

Strain B21.

All the strains of *Goghari* separated originally in 1914–15 and marked B were selected because of their tapering bolls, whic hwere supposed (as already remarked) to be connected with long staple in the lint. In the present case the boll was, however, only medium size. It was considered as promising in the following year, and was obtained pure in 1916–17 so far as the boll characters are concerned. The strain has turned out to be of a very leafy character. The plants are not only leafy, but give more monopodia than the strains hitherto described. The most frequent number of thise typ of branch is six, and hence it is more bushy. As a result apparently of this, the percentage of bolls borne on the primary fruiting branches is less than in any other of our pure strains (page 94).

The special characters of the produce of this strain are as follows :—

(1) The bolls are medium in size, and distinctly tapering. They open more widely than in any strain that we have isolated, but the valves do not recurve. The average weight of *kapas* per boll was :—

	Grm.
(*a*) in 1916–17	1·73
(*b*) in 1917–18	1·88
(*c*) in 1918–19	1·84

(2) The *kapas* gave a ginning percentage and lint-index as follows :—

Year	Ginning percentage	Lint-index
1916–17	45·4	4·01
1917–18	42·6	3·98
1918–19	45·0	4·30
1919–20	44·8	4·60

It will be noticed in 1919–20 that although the ginning percentage has gone down, the lint-index has gone up.

(3) The seed was of average size and 100 seeds weighed as follows :—

	Weight of 100 seed Grm.
1916–17	4·83
1917–18	5·36
1918–19	5·27
1919–20	5·67

(4) The lint gave the following average measurements on different parts of the seed in 1920 :—

	Centimetres
Lint on tip of seed	1·65
Lint on middle of seed	1·96
Lint on base of seed	1·82

The variation from the mean (*a*) at the tip was 8·8 per cent. below, (*b*) in the middle 8·2 per cent. above, and (*c*) at the base 0·5 per cent. above.

The lint on the middle of the seed varied as follows :—

Number of measurements made			100
Staple of	1·2	centimetres	1
Do.	1·3	Do.	0
Do.	1·4	Do.	0
Do.	1·5	Do.	1
Do.	1·6	Do.	2
Do.	1·7	Do.	4
Do.	1·8	Do.	18
Do.	1·9	Do.	23
Do.	2·0	Do.	20
Do.	2·1	Do.	15
Do.	2·2	Do.	10
Do.	2·3	Do.	6

The staple in this case is, therefore, shorter than in either A26 or B3 and is also very uneven even more so than B3. The variation is illustrated by Fig 4.

The lint, on examination by Messrs. Tata & Sons, Bombay, gave the following values :—

Year	VALUE OF LINT PER *candy* OF 784 lb		
	Fine Broach deshi	B21	A26
	Rs.	Rs.	Rs.
1916–17	500	460	..
1917–18	950	825	..
1918–19	600	450	450
1919–20	500	300	300

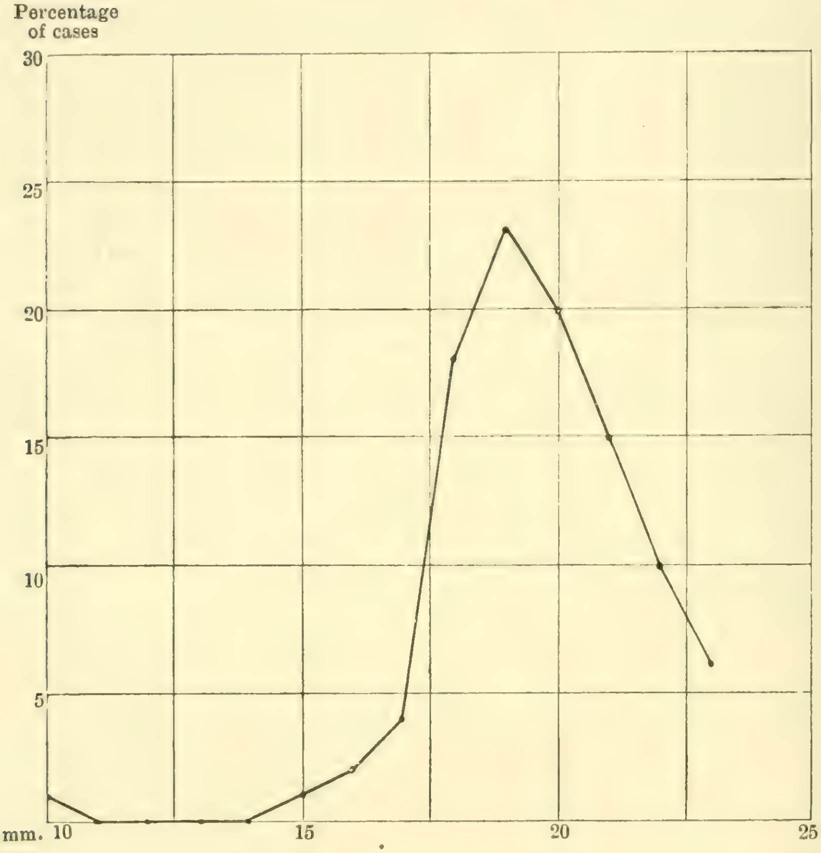


Fig. 4. Variation in length of staple in the middle of the seed in *Goghari* B21.

The strain so described is a very heavy yielder in an ordinary year, the best in fact among our strains, but in a year of drought it is much affected and the yield decreases more in proportion than with the strain E5. The bolls open well, which is also an advantage as this means ease of picking. These are its only advantages for with its low and very uneven staple—though it may be useful for crossing in order to get higher yield in a district of good rainfall—; it is, as it stands, a very low class of *Goghari* cotton.

Strain C22.

All our strains which have been marked as "C" were originally selected in 1914–15 on the basis of a small spherical boll. These were picked because Middleton (*loc. cit.*) suggests that under the name of *Gundi Goghari* types of cotton with small and round bolls gave cotton of quality higher than the average. It was obtained pure so far as boll characters were concerned in 1917–18, and has bred true since then. Its chief character as a plant has turned out to be lack of leafiness. The plants, though not leafy, are bushy and give monopodia varying in number from two to nine ; the most frequent number of this type of branch is five, and in this matter it is similar to A26 previously described. The flowering was early as is shown by the following figures for flowers produced on twelve plants (*cf.* B3 previously given on page 103) in 1918–19.

Number of flowers	from October	11 to 17	214
Do.	do.	18 to 24	134
Do.	do.	25 to 31	141
Do.	from November	5 to 10	130

The flowering started earlier, but continued as late as other strains, so that its flowering period was longer. As a result of this, it yields the best in dry years, as the earlier formed flowers, which inevitably fall if rain occurs, are able to form bolls successfully.

The special characters of the produce in this strain of cotton are as follows :—

(1) The bolls are spherical and small, and the number on each plant is greater. The opening of the bolls is poor, showing a tendency to be more of the *Wagad* type. The weight of the *kapas* per boll was :—

	Grm.
(*a*) in 1917–18	1·78
(*b*) in 1918–19	1·61

(2) The *kapas* gave a ginning percentage and lint-index as follows :—

Year	Ginning percentage	Lint-index
1917–18	42·4	3·88
1918–19	45·7	4·33
1919–20	47·6	4·80

The figures show a tendency under the conditions of the last two years for both the ginning percentage and lint-index to increase.

(3) The seed was of smaller size than the types previously described, and 100 seeds weighed as under :—

	Weight of 100 seeds Grm.
1917–18	5·27
1918–19	5·15
1919–20	5·29

(4) The lint gave the following average measurements on the different parts of the seed in 1919–20:—

	Centimetres
Lint on tip of seed	1·59
Lint on middle of seed	1·91
Lint on base of seed	1·76

The variation from the mean (*a*) at the tip was 9·1 per cent. below, (*b*) at the middle 9·1 per cent. above, and (*c*) at the base 0·6 per cent. above. It was hence more uneven than the strains previously described.

The lint in the middle of the seed varied as follows, as determined from one hundred measurements made on seeds. It is shown in Fig. 5.

Number of measurements made			100
Staple of	1·5	centimetres	3
Do.	1·6	Do.	5
Do.	1·7	Do.	4
Do.	1·8	Do.	21
Do.	1·9	Do.	20
Do.	2·0	Do.	25
Do.	2·1	Do.	17
Do.	2·2	Do.	5

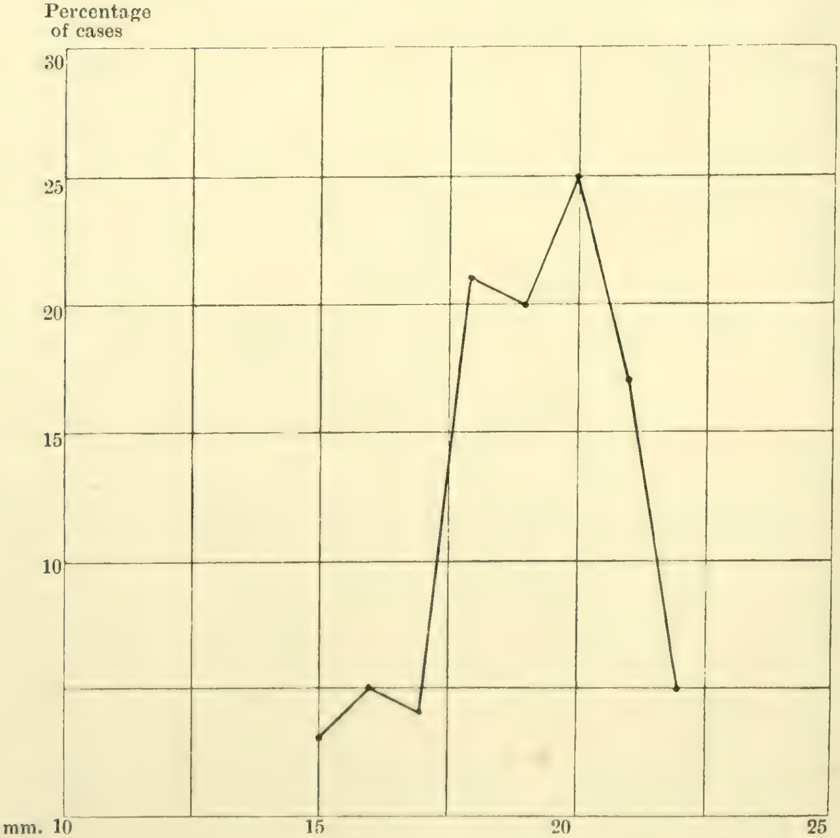


FIG. 5. Variation in length staple on the middle of the seed in *Goghari* C22.

The staple in this strain is shorter than in A26 and almost similar to B21. It is obvious that there is no necessary connection between the small boll and high quality cotton as was suggested by Middleton.

The lint on examination by Messrs. Tata & Sons, Bombay, gave the following values :—

Year	VALUE OF LINT PER *candy* OF 784 lb.		
	Fine Broach deshi	C22	A26
	Rs.	Rs.	Rs.
1917–18	950	775	..
1918–19	600	450	450
1919–20	500	280	300

On the whole, the strain may be described as a heavy yielder in dry years, the best, in fact, among our strains. In ordinary years it yields only moderately. Its ginning percentage is higher in fact than any except E5. These are its only advantages, for it has a low and very uneven staple. It might, however, be useful for crossing to get a higher yield and higher ginning percentage for the drier tracts. It is, as it stands, a very low class of *Goghari* cotton.

Strain E5.

This strain of *Goghari* cotton, whose ginning percentage is so high as to place it in a class by itself among *herbaceum* cottons, and which promises to be a very valuable discovery for purposes of crossing with strains of *Broach deshi* with better staple, was selected in 1914–15 from a plant bearing bolls intermediate in shape between the spherical 'A' and 'C' types and the tapering 'B'. It has been studied in greater detail than the other strain as its importance may be considerable in the future. It was obtained pure in 1917–18 and has been maintained so since that time, the boll characters breeding true in each generation.

The plants of this strain are of a less bushy character than those previously described. The number of monopodia varies from none to eight, the most frequent being three to four. This character appears to be constant from generation to generation. The rate of growth of monopodia indicates that it is a late type of cotton in an ordinary year, but that after three months these monopodia grow very rapidly indeed. This is on the whole an advantage as late growth and development of flowers are, in Lower Gujarat, an indication that there will be less shedding of flowers or bolls owing to rain. In the fourth month the rate of growth of the main stem and of the monopodia was equal counted in nodes. The relative growth counted in nodes, at the time when the flowering was just commencing in 1919, on the different types of branches was as follows :—Monopodia : Primary fruiting branches : Axillary vegetative shoots growing on primary fruiting branches : Axillary vegetative shoots growing on the main stem (The growth of vegetative shoots on monopodia, axillary vegetative shoots growing on primary fruiting branches and on axillary vegetative branches on the main stem were not noted) 1 : 1·5 : 0·4 : 1·5.

It must be recognized that there is a large seasonal factor in such a figure, however, and stress must not be laid upon it as characteristic of the strain.

The growth of primary fruiting branches is particularly vigorous in this strain, and is very regular ; as a result they give rise to an exceptionally large number of axillary shoots rising from axils at various points in their length, a very peculiar character in this and other strains which are especially vigorous in the development of such primary fruiting branches. Such axillaries grow much more rapidly than the original fruiting branch and produce several short new fruiting branches, so that they also increase to a considerable extent the rapidity with which the flowers are produced. This is very marked in a year when the rain tends to cause late flowering, and almost disappears in a year of drought.

Generally speaking the characteristics just described are desirable for a type of cotton in the area under consideration. It secures, if there is a dry season, that the flowers formed directly on the vigorous primary fruiting branches should form bolls, and at the same time, if these fall owing to unseasonable rain, there will be at least as many bolls, rapidly formed later, on the special axillary shoots rising from them as described above. It means, therefore, that the proportion of the total bolls on the plant which are borne on the primary fruiting branches and the axillaries which rise from them is far more constant than could otherwise be the case. The figures actually obtained with the present strain in the two very different seasons of 1918–19 and 1919–20 are as follows : 1918–19 was a year of very severe drought : 1919–20 was a normal season, except for late rains in January.

Proportion of total bolls in the plant which are borne on primary fruiting branches and their axillaries.

	Per cent.
1918–19	34·3
1919–20	33·1

The special characters of the produce in this strain of cotton are as follows :—

(1) The bolls are intermediate in character between the large tapering and the large spherical type. The opening is complete. The weight of the *kapas* per boll is :—

	Grm.
(*a*) 1917–18	2·25
(*b*) 1918–19	1·60 } *
(*c*) 1919–20	1·41 } *

(2) The *kapas* gave a ginning percentage and lint-index as follows :—

Year	Ginning percentage	Lint-index
1917–18	46·5	4·76
1918–19	49·3	5·23
1919–20	51·5	5·73

The ginning percentage of 1919–20 is probably above the normal for the strain, as part of the first picking was lost owing to late rains. But, in any case, the ginning percentage of this strain is remarkable, and it may be relied on to give between 46 and 50 every year. This is an extremely valuable quality and one of which use can be and is being made in crossing.

(3) The seed was an average *Goghari* size. One hundred seeds weighed as follows :—

	Weight of 100 seeds Grm.
1917–18	5·44
1918–19	5·39
1919–20	5·39

(4) The lint is very coarse and poor and gave the following average measurements in 1919–20 :—

	Centimetres
Lint on tip of seed	1·40
Lint on middle of seed	1·71
Lint on base of seed	1·55

The variation from the mean (*a*) at the tip was 9·6 per cent. below, (*b*) at the middle 10·3 per cent. above, and (*c*) at the base it was exactly the mean value. The lint was, therefore, very uneven on the seed.

The lint in the middle of the seed measured as follows, as determined from one hundred measurements made on seeds. The variation is shown in Fig. 6.

Staple of	1·3	centimetres	1
Do.	1·4	Do.	0
Do.	1·5	Do.	8
Do.	1·6	Do.	27
Do.	1·7	Do.	28
Do.	1·8	Do.	19
Do.	1·9	Do.	12
Do.	2·0	Do.	4
Do.	2·1	Do.	1

---

* In both these seasons there was a very large amount of shedding of bolls, in 1918–19 owing to the long drought and in 1919–20 to the late rain. These figures are hence not normal.

The staple of E5 is the shortest of all the selected strains, the bulk of the lint at the middle of the seed being only 1·6 to 1·8 centimetres long.

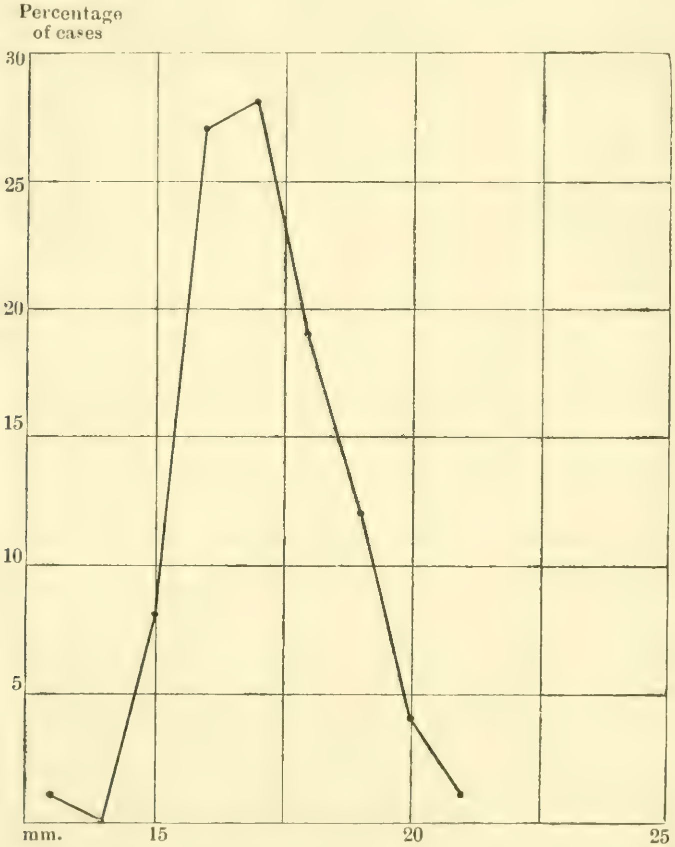


Fig. 6 **Variation in length of staple in the middle of the seed in *Goghari* E5. Produced from axillary limbs.**

This lint, on examination by Messrs. Tata & Sons, Bombay, gave the following values :—

Year	Value of lint per *candy* of 784 lb.		
	Fine Broach deshi	E5	A26
	Rs.	Rs.	Rs.
1917–18	950	825	..
1918–19	600	450	450
1919–20	500	280	300

On the whole, therefore, the strain may be described as a good yielding one, little affected by the character of the season, giving *kapas* of the highest ginning percentage known among *herbaceum* cottons, though the lint is short, coarse, and uneven. It is likely to have special value for producing a cross with *Broach deshi* cotton. For itself, it is almost worthless.

The relative characters of each of these strains, on the average, for the last two years is shown in the following table. *Fine Broach deshi* cotton is taken as being worth Rs. 500 per *candy*.

Strains	Yield of *kapas* per acre	Yield of lint per acre	Ginning percentage	Value per *candy*	Value per acre
	lb.	lb.		Rs.	Rs.
A26	331	147	44·2	337	63
B3	292	135	46·1	..	..
B21	455	205	44·9	337	88
C22	369	172	46·6	327	72
E5	414	209	50·4	327	87

7. *Comparison of the strains of* Goghari *cotton with pure-bred* Broach deshi *cotton.*

The description just given shows the characters of typical strains of *Goghari* cotton. It is now advisable to put besides them a detailed description of one of the typical strains of *Broach deshi* cotton, which we have isolated at Surat[1], and which breeds true. The strain was selected in *Navsari* cotton and has been bred pure under the name " 1027 ALF " since 1916-17.

The plant is bushy, bearing a number of monopodia at Surat of 1 to 10, the most frequent number being 6 to 7. Its vigour is less than that found in most *Goghari* cottons and this is particularly the case as regards the development of axillary shoots and branches, and also of primary fruiting branches.

The special characters of the produce of this first class strain of the *Broach deshi* cotton are as follows :—

(1) The bolls are large and tapering, being very similar to those of *Goghari* B3, except that the surface is smooth and the dark spots are absent. The opening of the bolls is very similar to the most open type of *Goghari*, the recurving at the edges of the valves being only slight ; the weight of *kapas* per boll is :—

	Grm.
1917–18	1·29
1918–19	1·49
1919–20	1·39

---

[1] Surat is forty miles distant from Broach where the *Goghari* types were grown.

This weight is smaller than in any of our strains of *Goghari*.

(2) The *kapas* gave a ginning percentage and lint-index as follows :—

Year	Ginning percentage	Lint-index
		Grm.
1916–17	33·3	2·84
1917–18	33·0	3·10
1918–19	37·3	3·37
1919–20	33·7	2·95

This shows the most obvious difference between the *Broach deshi* type and the *Goghari*.

(3) The seed was on the whole heavier than most types of *Goghari*. One hundred seeds weighed as follows :—

	Weight of 100 seeds
	Grm.
1916–17	5·68
1917–18	6·29
1918–19	6·06
1919–20	5·82

This is, however, not the characterstic of *Broach deshi* as a whole.

(4) The lint is long, fine, and silky, and it gave the following average measurements in 1919–20.

	Centimetres
Lint on tip of seed	2·16
Lint on middle of seed ..	2·69
Lint on base of seed	2·39

The variation from the mean (*a*) at the tip was 9·2 per cent. below, (*b*) at the middle was 9·6 per cent. above, and (*c*) at the base was 0·4 per cent. above. The lint was, therefore, not very different in its variation on different parts of the seed from that of *Goghari*. The lint on the middle of the seeds was varying as follows as determined from 100 measurements made on seeds :—

Staple of	2·1	centimetres	1
Do.	2·2	Do.	1
Do.	2·3	Do.	4
Do.	2·4	Do.	15
Do.	2·5	Do.	17
Do.	2·6	Do.	20
Do.	2·7	Do.	17
Do.	2·8	Do.	17
Do.	2·9	Do.	6
Do.	3·0	Do.	2

The staple is hence very much longer than that of any *Goghari* strain we know, the bulk of the lint at the middle of the seed being from 2·6 to 2·7 centimetres in length. This is illustrated in the figure below :—

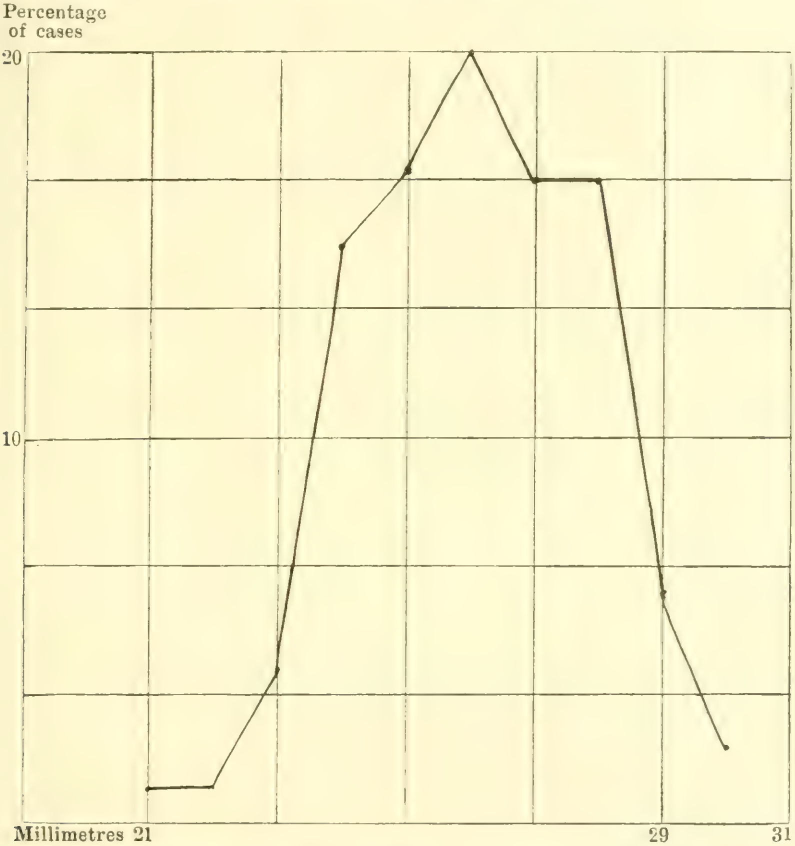


Fig. 7. Variation in length of staple on the middle of the seed in 1027 ALF.

The lint on examination by Messrs. Tata and Sons, Bombay, gave the following values :—

Year	Value of lint per *candy* of 784 lb.		
	Fine *Broach deshi*	1027 ALF	*Goghari* A26
	Rs.	Rs.	Rs.
1917–18	950	1,089	..
1918–19	600	762	450
1919–20	500	550	300

On the whole, therefore, if we compare this representative strain of the best *Broach deshi* cotton with the several *Goghari* strains which we have described, we have as shown in the attached table :—

Characters	*Broach deshi*	*Goghari*				
	1027 A L F	A26	B3	B21	C22	E5
(1) Number of monopodia	6–7	4–5	4–5	6	4–5	3–4
(2) Opening of bolls	Complete valves slightly recurved	Complete. No recurving	Complete. No recurving	Very complete. No recurving	Very incomplete. No recurving	Complete. No recurving
(3) Weight of *kapas* per boll in grm.	1·36	2·12	1·98	1·82	1·73	1·75
(4) Ginning percentage	34·3	44·2	46·1	44·9	46·6	50·4
(5) Lint-index in grammes	3·06	4·87	5·0	4·45	4·56	5·48
(6) Weight of 100 seeds in grammes	5·94	6·17	5·84	5·47	5·22	5·39
(7) Staple of lint at middle of seed in centimetres	2·69	2·01	1·94	1·96	1·91	1·71
(8) Relative value in 1920 per *candy* in Rs.	550	300	..	300	280	280

III. THE IDEAL TYPE OF *herbaceum* COTTON FOR LOWER GUJARAT.

Although the climate and soil conditions are sufficiently varying to make it probable that strains of cotton with somewhat different characters will furnish the best and most profitable types of cotton for different areas in Lower Gujarat, yet there are certain features, which our inquiries reveal which ought to be possessed by a cotton plant, which can be considered, as in any way satisfactory in any part of the area specified. These characters we shall have to describe, but before doing so, it is perhaps necessary to insist on two or three preliminary considerations.

It goes without saying, in fact, that any plant which is selected must be pure, and if possible consist of a pure line. This necessity has never really been adequately realized by growers or by traders, and as a result we have at present a mixture of types everywhere, some of which are suitable to the tract while some are not ; some give good staple cotton, some on the other hand are poor ; some give high, some low ginning percentage. Thus apart from any regular mixture of the three varieties previously noted, we have very extensive admixture of strains of cotton everywhere, which are of extremely different agricultural and commercial value. We wish to insist on this point because it is often supposed that provided the *Goghari* and *Wagad* types are eliminated, the *Broach deshi* which remains will be uniform and of high quality. This is by no means the case, and it is necessary that there should be available definite pure strains of the best variety of cotton for each tract which can be grown with certainty of the quality of the produce. This is not the case at present even when the so-called pure *Navasari* or *Surat* staple cotton is grown.

The second necessity of an ideal type of cotton is that the staple and ginning percentage should be as high as possible, consistent with a good yield of *kapas*. Up to the present, the possession of good staple has been considered as likely to occur with a cotton giving a poor ginning out-turn and generally poor yield in the field. All the definite evidence, however, would seem to indicate that there is no necessary connection between high staple and either low ginning percentage or low yield. With regard to the latter point an experiment was made in 1908–09[1] of transferring large quantities of *Broach deshi* seed from Navsari to Ahmedabad for cultivation. This, though the best stapled seed in the province, is in its own home a very low yielder, but at Ahmedabad it proved to be equal to local types of *Broach deshi* in this respect. Its ginning percentage remained lower than that of the local types grown, but there was no complaint that it did not yield equally well.

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[1] *Annual Report, Surat Agricultural Station*, 1908–09, p. 62.

With regard to the supposed connection between staple and low ginning percentage, the negative evidence is still more clear, and we have succeeded in obtaining strains of cotton which are at the same time of better staple than that usually grown, and which give a large ginning out-turn. The following table shows the average for ordinary *Surat* (*Broach deshi*) cotton grown at Surat in these particulars together with the figures for three strains which have been selected from it in 1919–20 :—

Type of cotton	Staple on middle of seed	Ginning percentage
	cm.	
Pure *Surat* cotton average	2·30	33·1
Selection 1A (cylindrical boll)	2·56	37·6
Selection 1A (long boll)	2·50	39·1
Selection 1027 ALF	2·61	33·9

These figures prove that an increase in staple and ginning percentage may be obtained at the same time, and if this is the case, it opens up possibilities for the development of cottons in both directions, hitherto not adequately realized.

But if we get pure cotton of the maximum ginning percentage and the greatest possible length of staple, there are certain characters in the plant in Gujarat *herbaceum* cottons which seem to be needed in order to obtain the best yield of bolls and hence of *kapas* under the climatic conditions of Lower Gujarat. To make the matter more clear, we may note that these cottons are sown in June and are reaped in January to March of the following year. Fairly general rain may be expected in a normal year until early October, with occasional showers later, though sometimes considerable rain falls after this time.

These characters are as under :—

1. The plants must be able to resist heavy rain when very young, that is to say, when they have less than six leaves. The character of the rainfall as well as the soil in Lower Gujarat is peculiar. The soil over the greater part of the cotton growing tract is of a heavy black type. Now this cannot be protected against excessive rains by being formed into small ridges, for the slimy character of the wet soil causes such ridges to disappear very quickly if the rapidity with which the rains come is such as to over-saturate the soil.

And the rain in the latter part of June and especially in the early part of July at Surat, for example, is such that excessive falls are very frequent ; if the plants are on small ridges these latter disappear and the plants are covered up ; if they are on the flat they are drowned by being compelled to remain in water-logged soil temporarily. Hence every year the mortality among the cotton plants is considerable and very often whole fields have to be resown. Some strains resist this drowning better than others. Among *Broach deshi* strains, we have one (Selection 1 A, cylindrical boll type plant) which resists better than any other we know. Similarly one of the strains of *Goghari* previously described (B21) is equally good in this respect.

2. The plants must possess the largest number of monopodia, *i.e.*, the vegetative branches formed in the lower part of the main stem, the number and vigour of which very largely determine the bushiness of the plant. They give rise to secondary fruiting branches, which bear a considerable proportion of the yield of the cotton plant in Gujarat, and as the flowers on these shoots generally appear at a time when they are not likely to be spoiled by rain, it is very important that they should be encouraged to the greatest possible extent. That there is a probable relationship (other things being equal) between the number of monopodia and yield is shown by the following figures for three strains of *Broach deshi* cotton at Surat in 1920, which differ markedly in this respect.

Strain	Number of monopodia	Yield of *kapas* per acre
		lb.
1 A cylindrical boll type	6	756
C1	5	693
1027 ALF1^3	4	517

This difference will be less marked in a very dry year as in 1918–19, but in a normal year such as occurs in eight years out of ten, the above figures will indicate what will certainly happen.

The reason of the advantage which the strain with many monopodia will show, lies in the fact that the cotton is planted in June and on account of the rain it is not desirable that flowers should appear in large numbers before the middle of November. We refer to this matter again under item 4 below.

3. *There should be the maximum development of vegetative branches on the plant (monopodia and axillary vegetative shoots arising from the main stem.)*

This is illustrated by the following figures, in which in 1919–20 we have measured the total growth of the vegetative branches in nodes, in three strains and compared them with yield.

Strain	Total growth of vegetative branches in nodes	Yield of *kapas* per acre
		lb,
1A cylindrical boll type ..	4,318	756
C1 type	3,863	693
1027 ALF	3,595	517

While these figures are not enough to prove absolutely the connection, yet they indicate the direction in which high yield is to be found in Gujarat.

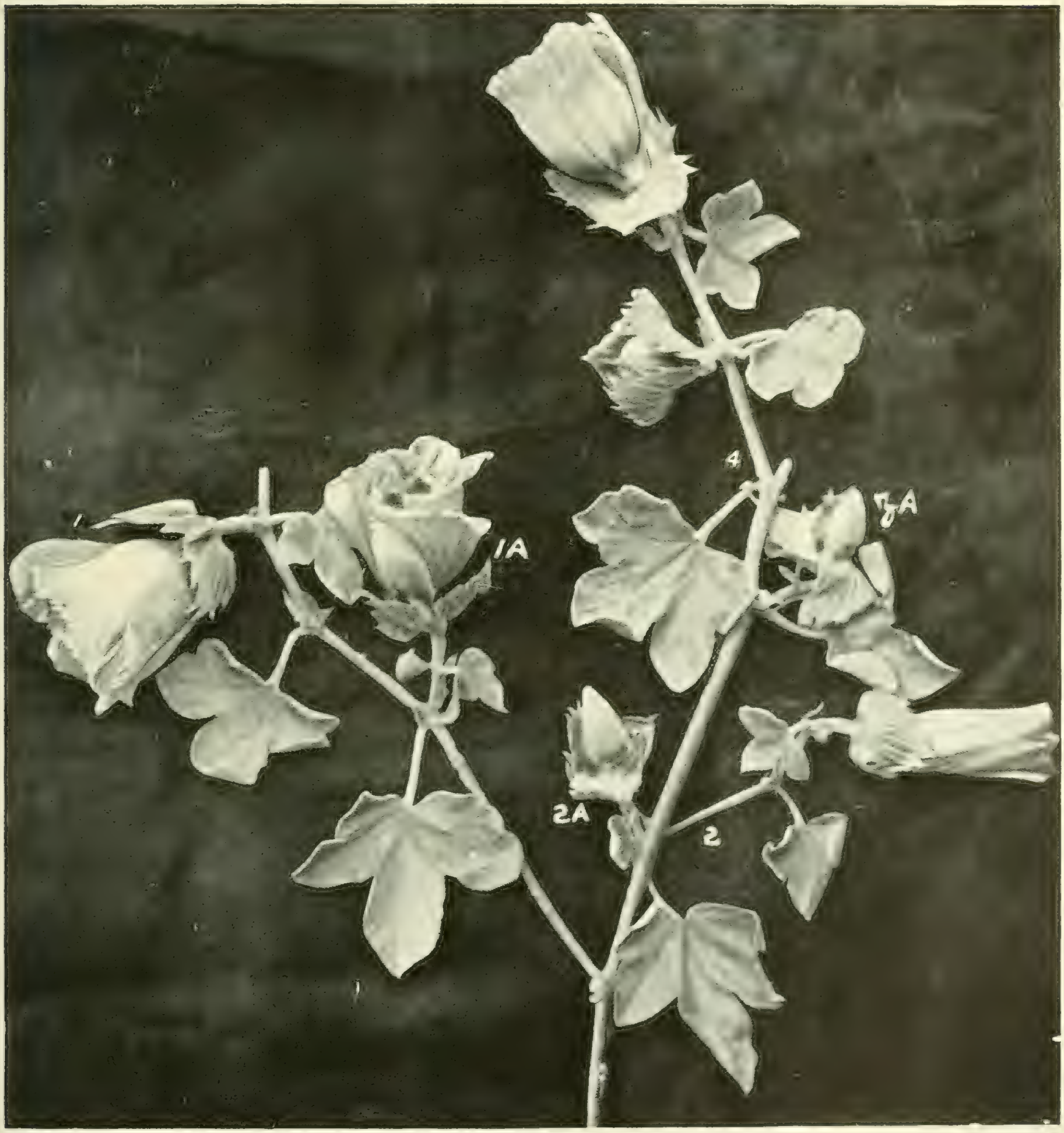
4. Flowering should not commence till November 15th and should be completed before the end of January.

The reason for this is that before the middle of November fine weather cannot be relied upon, and if rain or cloudy weather occurs, there is a very large shedding of flower buds. Hence it is wise to have a plant, if this is possible, which does not produce many flowers before that time. The flowering must be completed before the end of January, because the whole harvest must bé made before the end of March as, owing to the very high temperature during March, April, and May in Gujarat, there is a very large shedding of the immature bolls which remain on the plants. The most favourable time for the flowers to form is from the middle of December to the middle of January.

5. The bolls should be large and should open completely. The size of the bolls is a minor point but does lead to cheaper and easier picking. The complete opening of bolls makes picking so much easier that it is a matter of considerable importance.

These characters are not met with to an ideal extent in any of the cottons now cultivated. The nearest to them at present is reached perhaps in the 1A long boll type above referred to, and in some respects in 1027 ALF of *Broach deshi*, which is particularly suited for the Navsari area. These are hence being now multiplied on a large scale. But

PLATE VII.



Position of the accessory bud, right.

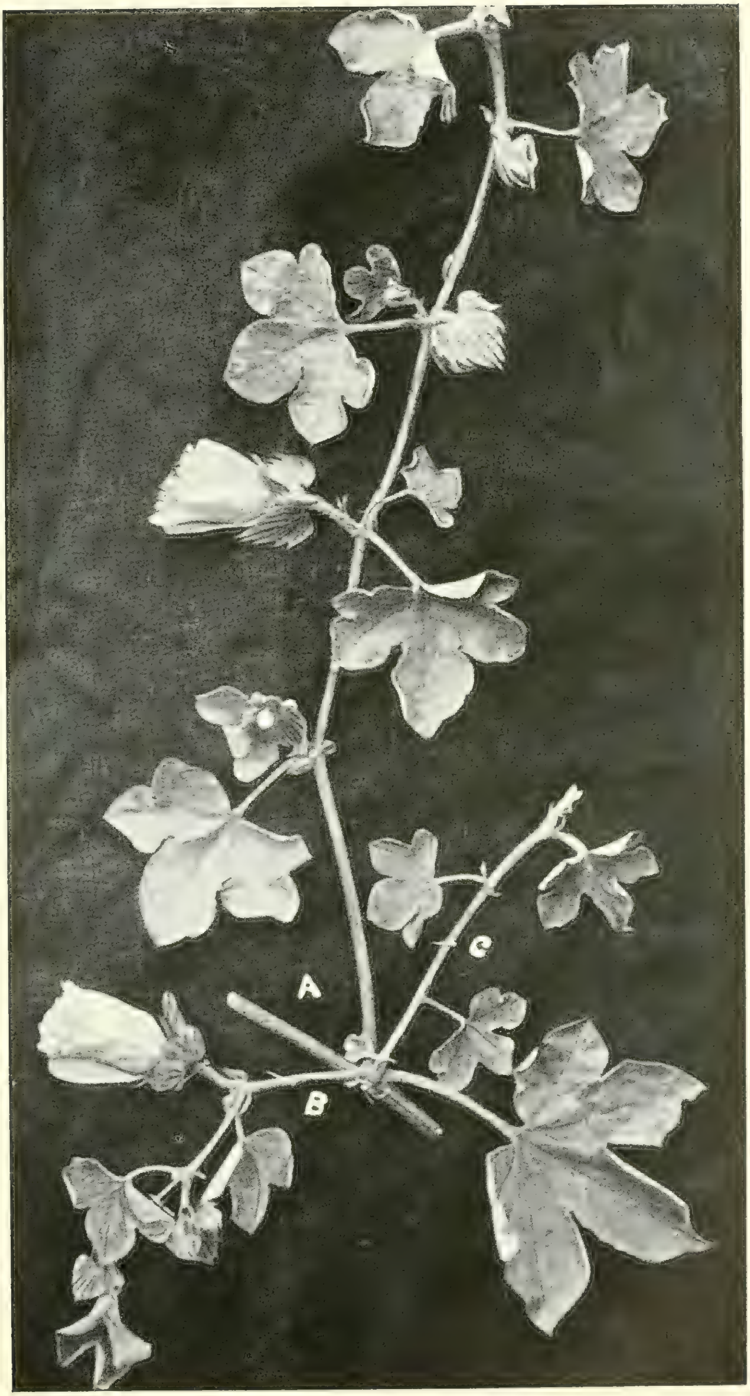
1, Primary fruiting branch with a flower at the third node. The spiral is against the hands of a watch.

2 & 4, Primary fruiting branches with a flower at the second node ; the spiral is by the hands of a watch.

1 A, Tertiary axillary limb having tertiary fruiting branch with flower at first node. The spiral is against the hands of a watch, *i.e.*, similar to (1) as it is at odd node.

2 A & 3 A, Primary accessory-fruiting branches with the flower at the first node; the spiral by the hands of a watch, even though at odd node (*i.e.*, opposite to 1A and 1).

PLATE VIII.



A shoot. The axil of a leaf having a primary fruiting branch, A; accessory primary fruiting branch, B; and axillary vegetative branch, C; position of the accessory bud, left.

A, Flower at the second node; spiral of the flower against the hands of a watch.

B, Flower at the first node and still the spiral is against the hands of a watch, because it is directly from

they are nevertheless deficient in some of the characters most to be desired, and if the ginning percentage could be built up by crossing with one of the *Goghari* strains, it is possible that new strains superior to either could be obtained. It is in this direction that work is now being largely done and in which future progress towards the ideal is now likely to be achieved.

ACKNOWLEDGMENTS.

I am under very considerable obligations to Dr. H. H. Mann, who drafted this paper from the results worked out by me.

APPENDIX.

CERTAIN MORPHOLOGICAL CHARACTERS IN *GOSSYPIUM HERBACEUM.*

1. The fate of accessory buds occuring in the axils by the side of primary fruiting branches in *Gossypium herbaceum,* may be of several kinds ; either such accessory bud may remain dormant as occurs in a good many of the buds near the base of the cotton plant, or it may develop into an axillary vegetative branch and this is what usually happens in the middle part of the main stem of the plant. There is, however, a third possibility that these accessory buds should develop directly into primary fruiting branches so that there would be two such primary fruiting branches arising from one axil. This third possibility has never been noticed on Indian cottons ; indeed Leake[1] has definitely stated that this does not occur in Indian types and that the branch from the accessory bud is never sympodial.

Burt and Haider[2] have found the character common however in Cawnpore-American cotton and they state that flowering branches are found to arise from flowering branches. This character is inherited regularly and appears in all plants of a race though in a varying degree and, when well developed, is often associated with the appearance of flowering branches from the accessory bud on the main stem, on the monopodia, as well as on the axillary vegetative branches near the top.

We have found that the phenomenon in question is very common also among plants of *Gossypium herbaceum* grown at Surat. A doubt might occur, however, as to the nature of these shoots arising from the accessory buds especially as Leake classifies such cases as apparent exceptions and state that they can be traced to local damage. That this is not the case, can, however, be clearly proved by a consideration of the æstivation of the flowers on the two primary fruiting branches arising from the main and accessory buds in the same axil, which should always be in the opposite direction to one another.

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[1] Leake and Ramprasad. "Studies on Indian Cottons, Part I—The Vegetative Characters." *Mem. Dept. Agri. India, Bot. Series,* VI, no. 4. 1914 : and also in "Observations on certain Extra-Indian Asiatic Cottons." *Mem. Dept. Agri. India, Bot. Series,* IV, no. 5, 1912.

[2] Burt and Haider. "Cawnpore-American Cotton." *Pusa Bulletin* no. 88. 1919.

If, however, the accessory bud had developed first into a vegetative branch however small, which had then given rise to a sympodium, the æstivation of the flower on such a sympodium would be in the same direction as on the primary fruiting branch arising from the main bud. In all the cases which we have examined, and such cases are very common in the upper part of the plant at Surat, the æstivation of the flowers is found to be in the opposite direction on the two primary fruiting branches arising from the node in one axil. This proves, we think, that in *Gossypium herbaceum* at Surat at any rate, both buds in an axil may form sympodia. Illustrations of such occurrences will be seen in Plates VII and VIII.

The following example will make the point clear :—

Suppose that the position of the accessory bud is on the right side of the main bud. The æstivation of the flower at the first node of the fruiting branch developing from the main bud, will be against the hands of a watch, while the æstivation of the flower at the first node of the fruiting branch developing from this accessory bud will be in the same direction as the hands of a watch.

In the case of the flower at the second node of the fruiting branch developing from the main bud it will be in the same direction as the hands of a watch, while in the case of the flower at the second node of the fruiting branch developing from the accessory bud, the æstivation will be against the hands of a watch. This rule is applicable at all further nodes.

The opposite is the case in both sorts of branches when the position of the accessory bud is on the left of the main bud.

2. *The leaf-factor.* In connection with the various species of *Gossypium*, the term " leaf-factor " was introduced by Leake[1] in order to define by a single figure the relationship between the breadth of the middle lobe of the leaf and the indentation of the leaf, and though some doubt has recently been raised by Kottur as to its simple character, yet it is a convenient figure for the purpose in question. There is a good deal of interest attached to the consideration as to how the shape of the leaf as thus described varies on different parts of the plant, and Leake has stated that in his observations the leaf-factor of the leaves on the primary fruiting branches is the smallest, on the main stem somewhat greater, while on the monopodia it is the largest of all. This relationship applies, according to Leake, to all types of cotton which he has examined.

So far as various strains of *Broach deshi* and *Goghari* types of *Gossypium herbaceum* grown at Surat and Broach are concerned, we have found, however, results which differ slightly from those noticed by Leake. According to our observations, while the leaf-factor of the leaves on the primary fruiting branches is the smallest (as Leake states) the leaves on the main stem themselves vary a good deal and the results differ with different varieties. While the leaves on the lower part of the main stem in *Broach deshi* have a smaller leaf-factor than those on the monopodia, those on the upper give a higher figure. In *Goghari*, on the other hand, our figures indicate that it is larger on the leaves of the main stem. The average figures for the different types of leaves in 1919–20 are as under :—

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[1] *Journal of Genetics*, 1, p. 220, 1910-11,

	Leaf-factor.	
	Broach deshi strains	*Goghari* strains
Primary fruiting branches	1·08	0·92
Lower portion of the main stem	1·14	1·14
Upper portion of the main stem (Leaves above the 15th leaf)	1·38	1·17
Monopodia	1·24	1·08

3. *Growth period of various types of branches.* There are, as has been frequently noted in connection with the cotton plant, four types of branches in connection with which flowers and bolls may be formed. The period of flowering and the length of time that the flowering lasts depends very largely on the relative development of each of these types of branches and hence it is of some importance to ascertain the growth period of each type as one of the factors which determines the yielding capacity of the plant. The various types of branches involved are :—

(1) The primary fruiting branches or sympodia.

(2) The monopodia or primary vegetative branches which bear secondary fruiting branches.

(3) The axillary vegetative branches occurring in the axil of the leaves on the main stem, by the side of the primary fruiting branches, which also bear fruiting branches.

(4) The axillary vegetative branches occurring in the axils of the leaves on the primary fruiting branches, which also themselves bear fruiting branches.

Now the first flowering in this type of cotton occurs on the primary fruiting branches, the next on the fruiting branches arising from the monopodia, and last come the flowers borne in connection with the axillaries. It has been stated by Leake[1] that, in his experiments on this type of *herbaceum* cotton, the vegetative period or the period between sowing and the appearance of the first flower was about 207 days, and he draws the contrast between this and the corresponding period in the sympodial cottons where it is 80 to 90 days.

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[1] *Mem. of the Dept. of Agri. India, Bot. Ser.*, VI, no. 4 (1914).

So far as Gujarat is concerned and with *Broach deshi* variety, we find that this vegetative period is much shorter than is stated by Leake. In 1918–19, when the long drought and low rainfall gave an opportunity for the first formed flower buds to develop, the vegetative period for *Broach deshi* strains was only 120 days.

In 1919–20, however, when owing to rain and bollworm attack, the first formed flower buds were destroyed, the period extended to 135 days. But both of these figures are far below that given by Leake, and it is probable that the exact time is very largely a matter of climatic conditions under which the cotton is grown.

The period during the growth of a *Broach deshi* plant required by the first branches of each kind as appeared at Surat, was as under in 1918–19 and 1919–20 :—

The first monopodium appeared in both years between 1 to 1½ months after germination ; the first primary fruiting branch was noticed between 1½ to 2 months ; the first axillary vegetative branch on the main stem appeared after 2 to 2½ months growth ; and the first axillary vegetative branch on the primary fruiting branches appeared after 4 to 4½ months.

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September 1921 Botanical Series Vol. XI, No. 5

Memoirs of the Department of Agriculture in India

DIE-BACK OF CHILLIES (*CAPSICUM* SPP.) IN BIHAR

[illegible] BY

JEHANGIR FARDUNJI DASTUR, M.Sc
Offg. Second Imperial Mycologist

AGRICULTURAL RESEARCH INSTITUTE, PUSA

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THE IMPERIAL DEPARTMENT OF AGRICULTURE IN INDIA

BY

THACKER, SPINK & CO., CALCUTTA
W. THACKER & CO., 2, CREED LANE, LONDON
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DIE-BACK OF CHILLIES (*CAPSICUM* SPP.) IN BIHAR.

BY

JEHANGIR FARDUNJI DASTUR, M.Sc.,
Offg. Second Imperial Mycologist.

[Received for publication on 23rd April, 1921.]

THE most serious disease of chillies (*Capsicum annuum* and *C. frutescens*) in Bihar is the die-back disease, due to *Vermicularia Capsici* Syd., which causes considerable damage to the crop, in years when there is continuous rain or high humidity in the latter half of September and beginning of October. In Bihar, the disease first appears in the end of September or in the first half of October, when the plants are mature and have commenced to flower. It spreads virulently from field to field. In severe cases of attack the plants are either completely killed or so badly diseased that the yield of healthy fruits is negligible. The first nip of the dry cold weather puts a sudden check to the progress of the disease which eventually dies away; the plants then recover and put forth new healthy shoots. The critical period when the plants are subject to the attack of the disease is, therefore, of a short duration, about four to six weeks.

Plants growing under shade have been observed to suffer very little from this disease. Late sown crops are also very little affected but unfortunately yield a very poor return. Fruits that mature before the beginning of December get badly diseased, to the extent of about 35 per cent., but those that ripen later escape the disease, the percentage of infected fruits after the middle of this month being negligible.

Macroscopic characters.

(*a*) *The stem.* The attack as a rule commences from the growing point or the flower-bud, and therefore the presence of the disease in the early stage of attack is marked by the top of the affected branches withering and turning brown (Plate I, fig. 2). The plant dies back as the attack spreads downwards:

when it reaches a fork the infection runs up the sound limb. In some cases the attack starts not from the growing point but from a wound on the stem. As the disease progresses, the infected part of the stem takes on an enamelled white colour and is sharply demarcated from the healthy green bark by a black line running round the whitened area. The white of the diseased part is punctuated by scattered black bristly and minute elevations, which are the acervuli of the fungus (Plate I, fig. 1).

(*b*) *The fruit.* The fruits become visibly diseased when they turn red, very seldom while they are still green. The first outward sign of infection is the appearance of a small black circular speck, generally sharply defined but at times diffused. The disease spreads not concentrically, but more in the direction of the long axis of the pod, so that the originally circular spot becomes more or less elliptical. As the infection progresses the spot is either diffused and black or greenish-black or dirty grey, or is markedly delimited by a thick and sharp black outline enclosing a lighter black or straw-coloured area. Two or more diseased spots may become confluent, thereby destroying the regularity of the individual spots, but the delimiting black line is not always completely obliterated where the infected areas have united. Badly diseased pods lose their normal red colour and turn straw-coloured or in some cases pale white (Plate I, fig. 3). The acervuli are generally densely gregarious or scattered all over the infected parts ; at times they are concentric. They project a little above the surface of the pod and are bristly and carbonaceous. The spores ooze out of the acervuli in pink masses or strings under moist conditions.

When a diseased pod is cut open the lower surface of the skin is found covered with minute, black, spherical elevations ; these are the stromatic masses or sclerotia of the fungus. In advanced cases the seeds are covered by a felt of white mycelium, in which are embedded a few black or grey-green stromatic bodies. Infected seeds turn rusty in colour.

Microscopic characters.

(*a*) *The stem.* Sections through a slightly diseased stem show the infected tissues to have turned yellow or brown and the cell cavities to be filled with a similarly coloured gummy substance which hides the hyphæ. The use of clearing agents helps in disclosing them. The tissues outside the xylem are more readily discoloured and destroyed than the xylem itself. Diseased xylem tissues get discoloured, but not so much as the soft outer tissues ; and the presence of the hyphæ within the vessels can be clearly traced. Even in very advanced cases of attack, the xylem vessels have not been found choked

EXPLANATION OF PLATE I.

Vermicularia Capsici Syd.

Fig. 1. A diseased stem, natural size.

,, 2. Early stage of die-back showing infection through flowers and flower-buds, natural size.

,, 3. Two diseased fruits, natural size.

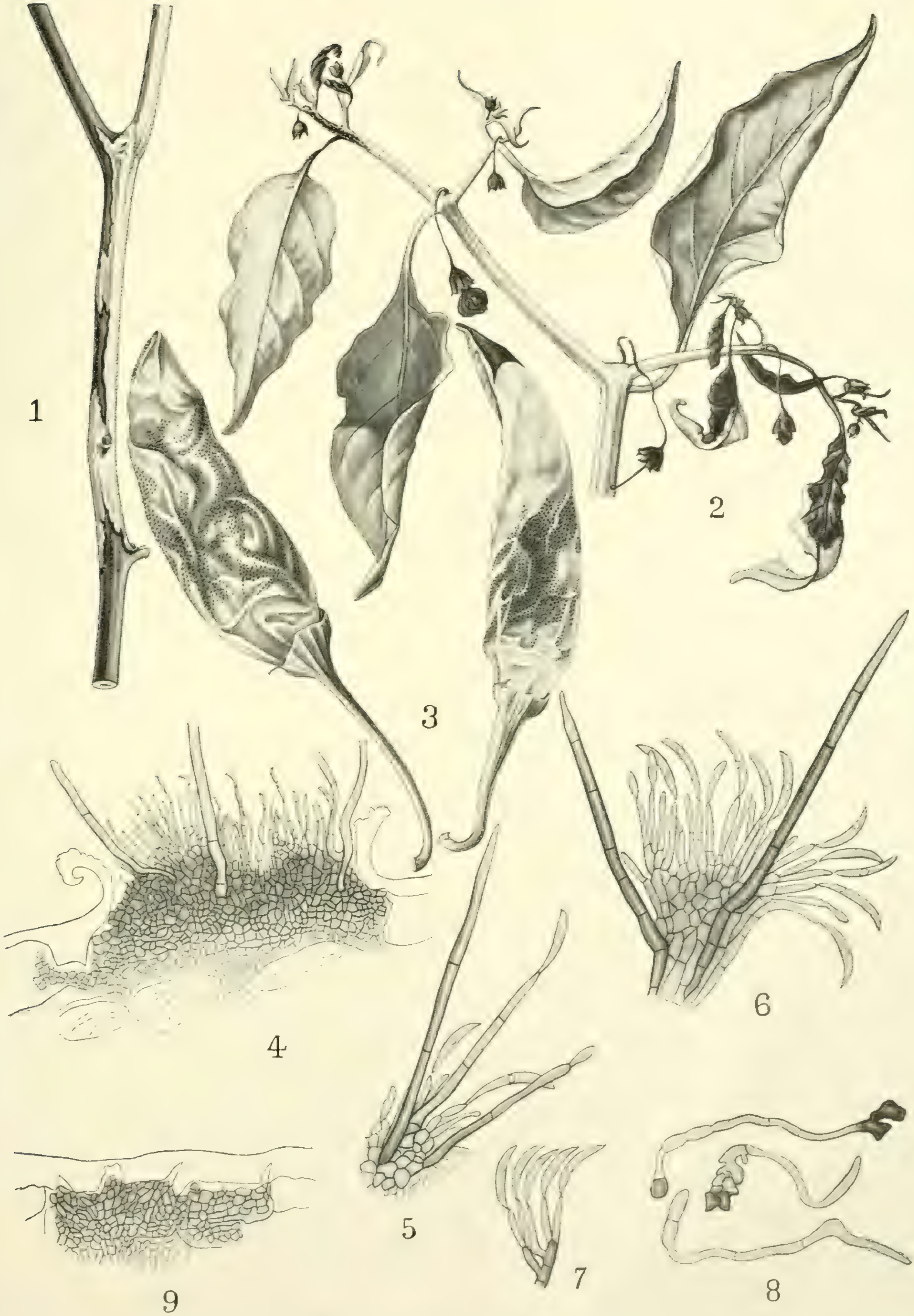
,, 4. An acervulus × 240.

Figs. 5-7. Parts of sporodochia × 503.

Fig. 8. Germination of conidia × 240.

,, 9. Stroma formation in the epidermal cells of fruits showing partial destruction of the cuticle × 327.

Figs. 6 and 7 have been reproduced from "Fungi and Disease in Plants" with the kind permission of the author, Dr. E. J. Butler.



VERMICULARIA CAPSICI SYD.

with the mycelium as in the vascular wilts, and this explains why a healthy leaf or pod is sometimes found attached to a stem completely ringed by the white diseased bark.

(*b*) *The fruit.* In the walls of the fruit the fungus overruns the soft tissues, destroying the cells. In the early stage of attack the cells are filled with a brown or yellow gummy substance which is not found at a later stage; the fungus also acts on the chromoplasts. The different colours of the diseased parts of the fruit are due to the quantity of the gummy substance present in the infected cells and to the extent to which the chromoplasts are altered. In the cells, a layer or two below the epidermis, the hyphæ commence to aggregate together, forming a loose mass of pseudo-parenchymatous cells, sub-hyaline or slightly brownish in colour. In the epidermal cells themselves a compact dark brown stroma of pseudo-parenchyma is laid down. Under the pressure of the growth of this stroma the cuticle is ruptured and lifted off the epidermal cells. The cuticle is not simply pushed up and ruptured by the fungus but is also partially eaten away (Plate I, fig. 9). On the surface of the brown stroma, now exposed to the air, a further development of lighter coloured fungus tissue, composed of elongated and narrow cells in almost parallel rows, occurs. The stroma of the acervulus is thus partly below the epidermis and partly above it (Plate I, fig. 4). The surface cells of the stroma become basidia (Plate I, fig. 6). The latter are hyaline, long and narrow. The conidia are hyaline, falcate, with an oil globule in the centre (Plate I, figs. 5—7). Setæ also arise from the pseudo-parenchymatous cells towards the surface of the stroma. They are abundant, simple, stiff, erect, septate and dark brown (fuliginous) in colour except at the tip which is lightly coloured. They occasionally bear conidia which are similar to those borne on the basidia (Plate I, fig. 5).

On the inside of the skin acervuli are not formed, but there are instead small round black or dark brown raised solid bodies composed of pseudo-parenchymatous cells formed by the conglomeration of hyphæ. These sclerotia-like bodies are also found on the thalamus.

(*c*) *The seed.* The inner walls of the normal cells of the seed coat are enormously thickened and finely striated. The outer wall is also thickened but very little in comparison with the other walls. This outer wall is composed of cellulose, while the inside walls contain both cellulose and lignin.*

---

* When treated with an acid solution of phloroglucin the inner walls of the seed coat show distinctly two layers. The centre of the thickened walls takes a red colour which shows the presence of lignin, while the rest of the thickened walls becomes light yellow in colour; but with Schulze's solution these parts stain blue, being composed of cellulose, and the centre stains yellow.

The fungus hyphæ enter the seed coat directly through the outer cellulose wall. The hypha, without necessarily forming an appressorium, bores its way through the upper wall and enters the cell cavity (Plate II, fig. 4). In badly infected seeds this upper wall has been very often found to be destroyed. The hypha now crosses the cell cavity and reaches the thickened inner walls. Here it swells at the point of contact, and from this swelling an exceedingly fine process is put forth which bores its way through, delignifying the wall (Plate II, fig. 5 . As the result of delignification, cellulose is left. That this happens is clearly seen by the action of Schulze's solution; the tunnels in the thickened walls formed by the hyphæ take a blue colour with this reagent.

Thus, unlike the hyphæ of *Macrosporium Solani* Cke.,[1] which infect the tomato seed through the micropyle, the hyphæ of *Vermicularia Capsici* Syd. enter the perisperm and endosperm directly through the seed coat.

In the infected chilli seed there is no formation of a thick weft of compact mycelium between the seed coat and the endosperm, as found by Miss Massee in the case of the hybernating mycelium of *Macrosporium Solani* Cke. in tomato seeds. Even in advanced cases of attack the testa of the chilli seed is in contact with the inner tissues except where stromatic bodies are formed in the cells adjacent to the seed coat which is consequently slightly lifted up at this place. The hyphæ are septate, of variable thickness, inter- and intracellular, and hyaline, but they turn brown when they collect in masses to form stromatic bodies. These bodies are composed of small pseudoparenchymatous cells. They are found both in the cells of the seed coat and of the inner tissues. Some sections of diseased seeds have shown fruiting pustules embedded in the inner tissues.

An infected seed in which the embryo is not attacked will germinate ; but conditions suitable for the germination of the seed are also favourable for the dormant stromatic bodies within the seed and on the seed coat to resume their activities ; these stromatic bodies have been found to remain viable for at least a year. Therefore there is the danger of the embryo getting diseased at any stage of its germination as long as any part of it is within the seed coat. The infection may spread through the diseased endosperm or from the outside of the diseased seed coat to those parts of the germinating embryo in contact with them. If the infection takes place when the cotyledons are still completely

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[1] Massee, J. On the Presence of Hybernating Mycelium of *Macrosporium Solani* Cke. in Tomato Seed. *Kew Bull.*, 1914, No. 4, p. 145.

EXPLANATION OF PLATE II.

Vermicularia Capsici Syd.

Fig. 1. A hypha penetrating the cuticular layer of the epidermis of a fruit by means of a fine lateral projection × 624.

,, 2. A hypha from an appressorium penetrating the cuticular layer through a natural crack in the epidermis × 624.

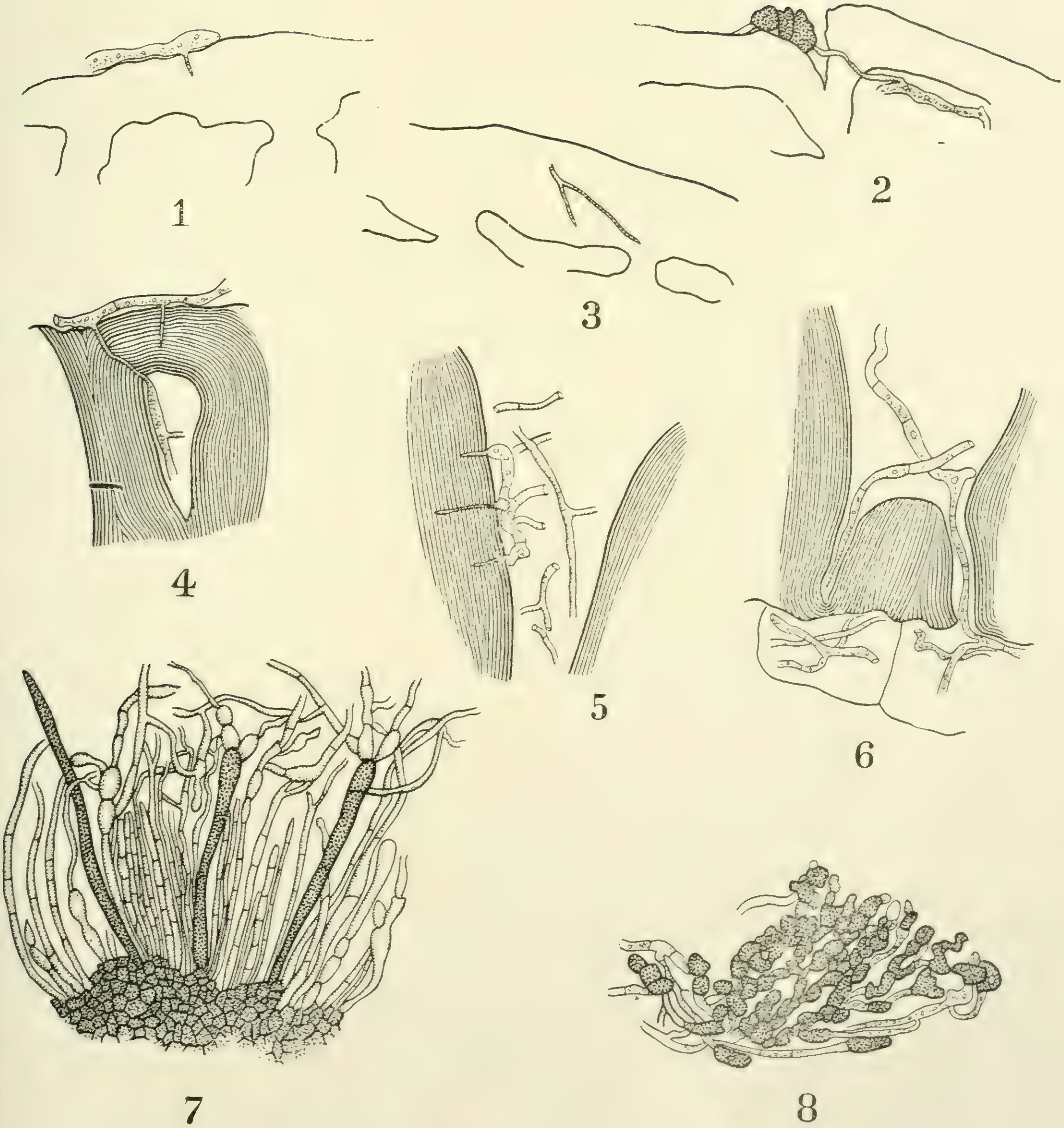
,, 3 A branched hypha in the cuticular layer × 624.

Figs. 4-6. Hyphæ in the cells of the seed coat × 576.

Fig. 7. An acervulus with setæ forming a pseudo-pycnidium (early stage) × 266.

,, 8. A group of appressoria forming a stroma × 266.

PLATE II.



VERMICULARIA CAPSICI SYD.

enclosed within the seed coat, the germinating embryo is killed almost at once. but if it spreads when only a part of the cotyledons are within the seed coat, the seedling may escape total destruction from the disease and may grow into a healthy plant, especially if the weather is dry enough to check the further progress of the disease.

Cultures of the parasite.

Shear and Wood[1] have found sterilized corn meal and corn-meal agar to be satisfactory media for growing the ascigerous stages of some fungi causing anthracnoses. Krüger[2] succeeded in getting the perfect stage of *Glœosporium musarum* on potato stems completely or partly sterilized.

Vermicularia Capsici has been cultivated many times on these media and on several others, but the perithecial stage has not as yet been obtained.

In agar media the early growth of the fungus is slightly ærial, white and floccose. As it grows it forms a thick leathery mat of interlacing hyaline hyphæ on the surface of the medium. In four or five days after inoculation black raised bodies like pin-heads are visible. These are either the acervuli or sclerotia of the fungus. A band of black or brown stromatic tissue is formed where the agar slant touches the glass slides. As the culture grows old, stromatic plates are laid down, closely in contact with the surface of the medium.

The ærial hyphæ are uniform in thickness and do not bear conidia like those of *Glœosporium piperatum.* The matted hyphæ on the surface of the medium and the hyphæ in its substance vary a great deal in breadth. Some are extremely fine, while others are very broad. The cytoplasm of the broad hyphæ, especially of those within the medium, is highly vacuolate. As the culture grows old, large hyaline vesicles appear as offshoots of the mycelium or short branches of the mycelium become very much enlarged at the tips. Daughter hyphæ occasionally arise through the septa from within the parent hypha. All hyphæ are hyaline except those that form acervuli, sclerotia and stromatic masses.

The acervuli in culture media appear as round black bristly heads. They are identical with those found on the host itself.

Pseudo-pycnidia. Acervuli, especially when old, are sometimes roofed over by a network of brown-coloured hyphæ formed by the profuse branching of some of the setæ and the marginal cells of the acervulus.

---

[1] Shear, C. L., and Wood, A. K. Studies of Fungous Parasites belonging to the Genus *Glomerella. U. S. Dept. Agri. Bur. Pl. Ind. Bul. No.* 252, p. 15, 1913.

[2] Krüger, F. Beiträge zur Kenntnis einiger *Glœosporien,* I and II. *Arb. Kais. Biol. Anst. f. Land-und Forstwirtschaft,* IX, Pt. 2, p. 271, 1913.

Sclerotia. These bodies are formed in two ways : (1) Hyphæ collect together and form a solid black ball. On sectioning, this is found to be composed more or less uniformly of brown pseudo-parenchymatous cells, but in some cases there is a slight differentiation into cortex and medulla ; the central cells are large and thin-walled and the peripheral cells have a smaller lumen and are thick-walled and deeply coloured. (2) At times what is potentially an acervulus is transformed into a sclerotium. As in the case of a normal acervulus, a base of brown-coloured pseudo-parenchyma is laid down. From this arise dark coloured setæ and parallel rows of light coloured thin and septate hyphæ which in the course of normal development would have borne basidia and spores ; interspersed with these fine hyphæ are found broad ones from which barrel-shaped cells are cut off. By the repeated branching of setæ and hyphæ and by formation of lateral outgrowths, a sclerotium is thus formed in place of an acervulus (Plate II, fig. 7). Sclerotia often have setæ like those of *V. varians* Duc. on potato.

Stromatic masses. In old cultures on agar media stromatic plates are laid down closely appressed to the surface of the medium. These plates are composed of brown septate hyphæ. They seem to be filled with some reserve material. When hyphæ from the agar medium come in contact with the sides of the tube they bear appressoria which run into chains (Plate II, fig. 8). These chains unite into small triangular black or brown stromatic masses which creep up the sides of the tube and form a band round the margin of the medium.

On sterilized stems of *Capsicum* sp. and potato very little aerial growth is formed. Sclerotia and acervuli are produced in abundance.

When the acervulus becomes old and dry it is covered by a mucilaginous hard coat which keeps the enclosed mass of spores viable for several months ; but the conidia are very short lived if they get separated from the mass. Spores germinate in ordinary water by giving out germ-tubes from near their ends. When the germ-tube has grown a short distance there is formed at its end an appressorium. In some cases the germinating spore divides by a septum at the middle and may become constricted at this point (Plate I, fig. 8). The germ-tubes do not anastomose as those of *Glœosporium piperatum* E. & E. They do not form secondary conidia on their tips or on lateral branches.

Sclerotia and stromatic masses may resume growth immediately under favourable conditions, but they are capable of retaining their vitality for several months. They "germinate" by giving out hyaline hyphæ from their cells.

Inoculation experiments.

All the inoculations were done with cultures originally started from a single spore.

Chillies. Seedlings grown in sterilized tubes containing moist cotton plugs from seeds removed aseptically from healthy chilli pods were inoculated either with spores or with hyphæ. The effect of the inoculations was noticed in three or four days by the inoculated parts turning brown. The infection spread rapidly and killed the seedlings in a couple of days ; *Vermicularia* acervuli were produced in abundance. The success of the inoculations and the spread of the infection depended upon the amount of moisture present in the tubes. If there was not sufficient moisture when the seedlings were inoculated, the inoculations did not take. If after the infections had started, the amount of moisture was reduced below a certain limit, the spread of the disease was checked.

Growing points and flowers of plants raised in pots were inoculated and kept under bell jars in the laboratory. The inoculations in some cases failed, and in others where the infection had started it did not make much progress ; but if the inoculated plants were kept in a moist atmosphere by covering the inside of the bell jars with moist blotting paper, the inoculations invariably succeeded and the infection spread rapidly, killing back the plant. The first signs of successful infection are the turning brown and rotting of the inoculated growing point or flower. As the infection spreads, the plant gradually dies back. Inoculations done on unwounded woody parts of the stem were unsuccessful ; wounded parts could be inoculated but not as readily and rapidly as the growing points and flowers.

Mature pods were readily infected but not the green fruits.

Microtomic sections of inoculated pods show that the hyphæ enter the skin directly or through natural cracks in the thick cuticle (Plate II, figs. 1 and 2) in the former case the hyphæ form an appressorium before entering the unbroken cuticle, unlike those attacking the seed coat ; a very fine process which penetrates the cuticle is produced from this appressorium. As long as the hypha is in the cuticle it remains exceedingly fine (Plate II, figs. 2 and 3) ; but it swells up to its normal size when it enters an epidermal cell (Plate II, fig. 2). It sometimes gets branched when within the cuticle.

Seeds of chillies have also been successfully inoculated. In the early stage of infection the seeds became rusty brown. Acervuli and sclerotia were formed on the seed coat and in the inner tissues as well under moist conditions.

Carica Papaya. Flowers of *Carica Papaya* have given successful inoculations. They showed in two days a brown, water-soaked appearance at the place of inoculation. *Vermicularia* acervuli were produced in four days; very young fruits could be inoculated either through wounds or through scars left by fallen petals. The beginning of the infection was marked by a circular depression at the inoculated part.

Vigna Catjang and Dolichos lablab. Pods of these vegetables did not take the inoculation so readily as flowers and young fruits of *Carica Papaya*. It was almost a week before the first symptoms of the infection were seen. The inoculated pods of *Vigna Catjang* became water-soaked while those of *Dolichos lablab* were depressed as the result of infection.

Solanum Melongena. Fruits of brinjal showed a slight browning in about ten days after inoculation which was done by wounding the epidermis. A little later the brown area became sunken and then black. The infected area was black in the centre and brown at the margins. Black acervuli were produced in the sunken areas and were arranged more or less concentrically.

Citrus sp. As the result of inoculation through a puncture a scabby growth was formed in a few days. This scab did not much increase in size and produced only a few scattered acervuli. Underneath this scab the tissues were rotting and had turned brown.

Inoculations on mango (*Mangifera indica*), plantains (*Musa* sp.), French bean (*Phaseolus vulgaris*), sweet peas (*Lathyrus odorata*), onions (*Allium cepa*), sugarcane (*Saccharum officinarum*) and *Sorghum vulgare* have failed.

Treatment.

It was at first supposed that seed selection would perhaps play an important part in controlling this disease, but the desired result has not been obtained under field conditions.

Healthy and infected seeds were sown in two separate seed beds. The germination of the infected seeds was poor, about 60 to 70 per cent.; and 10 to 15 per cent. of the seedlings died of the disease before the cotyledons had completely opened. The germination of the healthy seeds was normal and not a single seedling was infected. Seedlings grown from infected seeds showed a slightly poorer growth than those raised from healthy seeds and this difference could be observed for some time after the seedlings were transplanted in two separate plots in a field ; but it gradually wore off and at the time of flowering the plants in both the plots were equally vigorous. The field in which the plants were transplanted had never grown chillies before, and in fact was brought under cultivation only the previous year. Nevertheless, the disease appeared in both the plots by the middle of October when the plants had commenced to set fruit, and was equally severe.

Treating infected seeds with different strengths of copper sulphate solution and of formalin before sowing was also tried, but naturally the rate of germination was not higher as the fungus has been found to hibernate within the seed.

During the chilli season of 1917–18 eight ¼-acre plots were laid under chillies to try remedial measures that had suggested themselves in the light of experience gained in previous years.

The writer wishes to make his acknowledgments to Mr. G. S. Henderson, Imperial Agriculturist, for the assistance he has given in carrying out these experiments. Acknowledgments are also due to Md. Taslim, Fieldman to the Imperial Mycologist, for the care he has taken in looking after these experiments.

The plan of the experiments is shown in the following diagram:—

Bombay variety	Chillies grown with maize. One row of maize after every 3 of chillies	Control local varieties	Manured local varieties
1	2	3	4
Peshawar variety	Control local varieties	Local varieties sprayed with 1 p.c. Burgundy mixture	Manured local varieties late sown
5	6	7	8

On all the plots except on Nos. 1 and 5, local varieties were grown; plots 1 and 5 were under Bombay and Peshawar varieties respectively. Seeds for plots 1 to 7 were sown in seed beds in the end of June, and the seedlings were transplanted a month later. Seedlings for No. 8 were transplanted in the end of August, the seeds having been sown a month previous. The first four pickings of ripe fruits from plots 2, 3, 4, 6 and 7 were made on the 30th of October, the 12th of November, the 24th of November and 8th of December. Fruits from plot No. 8 were first picked on the 20th of December.

The yields were low as compared with those normally obtained. This was largely due to over-spacing, the plants being sown 24″ × 24″ apart as against the usual 18″ × 12.″ The soil was also poorer than that ordinarily used for the chilli crop, and the young plants were attacked by white-ants. The crop was put to a severe test on account of the unfavourable weather. From the middle of September to the first week of October, when the plants had commenced to flower, and consequently were in the stage when they are most readily infected, the days were cloudy and there was more or less rain almost every day. The relative humidity was therefore very high—between 85 and 96 per cent. Those were the conditions highly favourable for causing an epidemic, and there was one, judging from the amount of disease in the control plots and in the ryots' fields. Another factor which tried the efficiency of the control measures was the presence of a second disease, hitherto unobserved on this crop; this was due to *Choanephora Cucurbitarum* (B. & Rav.) Thaxt.[1] which caused much damage. It started from the flower or leaf-bud and led to a wet rot of the shoot.

In spite of these adverse circumstances, one of the control measures, *viz.*, spraying, gave satisfactory results.

To judge the effects of spraying and manuring on the disease on fruits we need only consider the results of the first four pickings done up to the 8th of December, because after this date the percentage of diseased fruits was found to be negligible.

	Weight of fresh *healthy* fruits		Weight of fresh *diseased* fruits		Total weight of fresh fruits		PERCENTAGE OF DISEASED FRUITS				Total percentage of diseased fruits	The date when the disease was first observed
							1st picking on 30th October	2nd picking on 12th November	3rd picking on 24th November	4th picking on 8th December		
	lb.	oz.	lb.	oz.	lb.	oz.						
(1) Bombay variety	..	..	..	..	..	..	..	..	..	..	..	15th October.
(2) Chilli and maize	25	4½	9	12¾	35	1¼	68·5	22·0	44·0	7·7	27·4	27th September
(3) Control	38	6	20	8	58	14	78·5	30·0	33·0	12·8	34·3	5th October.
(4) Manured	207	0	51	10½	258	10½	25·0	17·5	25·4	17·3	19·8	8th October.
(5) Peshawar	..	..	..	...								....
(6) Control	104	12	57	5½	162	1½	72·8	33·3	37·0	16·6	35·4	8th October.
(7) Sprayed	120	8	10	7½	130	15½	11·6	7·5	10·0	7·5	7·4	10th October.
(8) Manured late sown	..	..	..	..	..	..	..	..	..	..	..	26th October.

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[1] Dastur, J. F. *Choanephora Cucurbitarum* (B. & Rav.) Thaxter on Chillies. *Ann. Bot.*, XXXIV No. CXXXV, 1920, p. 399.

Plot Nos. 1 *and* 5. As the *Vermicularia* disease is very common on varieties of chillies grown locally, seeds from Bombay and Peshawar, where this disease has not as yet been reported from, were tried in order to see if plants raised from them were disease resistant. Unfortunately these varieties did not do well here ; the growth of the plants was stunted and the yield of fruits negligible ; the Bombay variety suffered badly from leaf-curl as well.

Plot No. 2. In fields lined by a row of trees those plants that grow within the shadow-limits of those trees have been found to be healthy, while those planted outside the shadow-limit get badly attacked by die-back. Small wayside chilli plots surrounded by huts or by big trees have been observed to be free from the disease when other plots a little further away but in the open become infected.

The reason why plants growing under shade remain healthy while those in the open are affected is, that moisture plays a very important factor in the development and spread of the disease. In October and November night dews and ground fogs are heavy and the plants consequently become dripping wet in the night and remain so for some time after sunrise ; this high humidity is favourable for the spread of the disease. But under shade there is very little mist or dew-fall, and consequently here the atmosphere is comparatively dry, dry enough to check the spread of the disease.

Inoculation experiments under laboratory conditions have shown that a great deal of moisture is required for the inoculations to succeed and for the infection to spread further. If a successfully inoculated plant or fruit is removed to dry surroundings the infection does not progress. Thus laboratory study has confirmed field observations.

As a result of these observations another line of control suggested itself. It seemed probable that if chillies were grown as a mixed crop with maize or some such other economic crop, which grows rapidly and gives a good shade, the chilli crop would perhaps remain healthy or would be very little affected.

For this reason the local varieties of chillies were grown mixed with maize. Drills of maize were laid down after every three rows of chillies. Maize was sown in drills in the end of July when the chilli seeds were sown in seed beds. The selection of maize as a mixed crop was unfortunate ; it flowered and cobbed in September and in the beginning of October it began to turn brown ; again in the first week of this month it was blown over in the high winds and damaged the chilli plants. It was consequently uprooted two or three weeks later.

The chilli plants were rather smaller in size, flowered later and gave comparatively smaller yield of fruits than those of the control plots. They also showed a greater amount of leaf curl. However the effect of shade as far as the disease on the chilli stems was concerned was very marked. They suffered the least from die-back. That shade does check die-back is also evident from the following observation. It so happened that the three end lines of chillies had no drill of maize to their south and so they remained unshaded. The result was that this set of three lines was more badly attacked than the rest. It had 32 plants suffering from die-back; the neighbouring set of three rows had 11 diseased plants, while in the remaining 9 sets the number of died-back plants varied from 6 to 9 each set. It was in the unshaded rows that the disease first appeared.

Whether shade has any effect on the total yield and on the percentage of diseased fruits cannot be judged from this experiment because, as already stated, maize plants were blown over by high winds in the beginning of October and they were uprooted three weeks later, as instead of doing any further good they were damaging the chilli plants underneath them. Thus at the time when the fruits generally get attacked they remained unshaded. The percentage of diseased fruits in each of the first four pickings was 68·5, 22·0, 44·0 and 7·7, almost the same as that for the control plots.

Plot Nos. 3 *and* 6. These were control plots. Of all the plots, plot No. 3 was most severely attacked by *Choanephora* and die-back; the natural result was that the yield of fruits was greatly reduced; the attack was first observed on the 5th of October. Plot No. 6 was found attacked three days later. It was a little more diseased than the sprayed plot No. 7, but much less than No. 3. Still however the percentage of diseased fruits in both these control plots was almost the same, and much higher than that in the sprayed plot. The percentage of diseased fruits from each of the first four pickings from plot No. 3 was 78·5, 30·0, 33·0 and 12·8, and from No. 6 was 72·8, 33·3, 37·0 and 16·6.

Plot Nos. 4 *and* 8. From experiments made in previous years it had been found that chillies sown a month later than usual suffer very little from die-back, but the yield of fruits was greatly reduced. To see if manuring could remedy this defect, plot No. 8 was manured at the rate of 2 cwt. of superphosphate and 1 cwt. of nitrate of soda per acre. Seeds for this plot were sown in seed beds in the end of August, and the seedlings were transplanted a month later. Plot No. 4, which was manured at the same rate, served as a check, the sowing time being normal.

As a result of manuring the growth of the plants in plot No. 4 was more vigorous than those in the other plots. Die-back on this plot was observed first on the 8th of October; and it was rather severe, but was not very much more than on plot No. 6 and decidedly less than that on No. 3. The total yield of fruits was much heavier than in any of the other plots, and the percentage of diseased fruits was less than that from the control plots, but more than that from the sprayed plot. The percentage for each of the first four pickings being 25·0, 17·5, 25·4 and 17·3.

On plot No. 8 the disease was first observed on the 26th of October. Altogether only 45 plants were found infected by the end of November. This showed once again that a late sown crop easily escaped damage caused by die-back. The fruits were not ready for picking before the third week of December, and therefore naturally the percentage of diseased fruits was negligible.

Plot No. 7. The disease on this plot was first observed on the 10th of October, but the first application of one per cent. Burgundy mixture, at the rate of 125 gallons per acre, was given on the 29th of September as on the 27th one plant in plot No. 2 was found diseased. The mixture happened to be very alkaline, and consequently the tender tips of the flowering shoots got rather badly burnt. The next application was given on the 17th when the fruits had set. It had no bad effect on the plants as the mixture was made very slightly alkaline. The sprayed plants had decidedly less of die-back than the plots 3, 4 and 6, and yielded more healthy fruits. The percentage of diseased fruits for each of the first four pickings was 11·6, 7·5, 10·0 and 7·5. The total yield of fresh fruits from these pickings was less than that of the control plot No. 6, but the yield of healthy fruits was higher. Not only did the freshly picked fruits from the sprayed plot compare favourably in regard to the percentage of disease than those from the unsprayed plots, but they also stood drying better. Healthy fruits picked from the sprayed plot remained healthy on drying, and the skin of the dried fruits was bright ruby red. But fruits from unsprayed plots that were healthy when picked developed diseased spots on drying. It has been found that *Glœosporium* on plantains[1] and on other fruits and leaves[2] is capable of lying dormant till there are suitable circumstances for developing its activities ; similarly *Vermicularia* may lie dormant on the pods and resume its growth in the moist and warm conditions of the drying heap ; of course, the attack of the disease on the drying pods is not very severe, but the spotted and discoloured skin of the dry fruits is bound to lessen the market value.

The reason why only two sprayings were given is that before the third could be applied there was a sudden fall of temperature and of the humidity percentage in the beginning of November and the disease was consequently checked. The disease did not progress further down the infected part of the plants, and no fresh infections on the plants were observed after the cold weather. That the disease was checked is also evident from the fact that in the first picking the percentage of diseased pods in the plots 3, 4 and 6 was 78·5, 25·0 and 72·8 respectively, while in the second picking the percentage fell to 30·0, 17·5 and 33·3 for the respective plots. It was further found that better results are obtained if the diseased parts of the plants are thoroughly pruned off before spraying, as the fungicide is applied only as a preventive measure and not as a curative. The fungus hyphæ once inside the tissues are little harmed by the application of any spray; therefore the spread of the fungus from within the diseased tissues to the neighbouring healthy parts and the ultimate death of the plant cannot be prevented; the spray only checks new infections from outside. However, it is doubtful if the pruning of diseased shoots is practicable on a field scale.

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[1] Dastur, J. F. Spraying for Ripe Rot of the Plantain Fruit. *Agri. Jour. India*, XI, 1916, p. 145.

[2] Shear, C. L., & Wood, A. K. Studies of Fungus parasites belonging to the Genus *Glomerella*. *U. S. Dept. of Agri. Bur. of Pl. Ind. Bull. No.* 252, 1913, p. 95.

From the above experiments the following deductions can be drawn :—

1. That the disease appears after the end of the rains—in the first and second week of October; that it attacks plants only at a definite stage in their growth, *i.e.*, when the flowers have set, and that it disappears as soon as the cold weather commences in the beginning of November; the disease on the plant is, therefore, of a very short duration. Fruits that mature before the beginning of December are much damaged by the disease, but the percentage of infection on fruits that ripen later is negligible. These observations are completely in accord with those made in the ryots' fields. It seems, therefore probable that if a late maturing variety could be successfully grown in Bihar it would escape the disease.

2. That Bombay and Peshawar varieties do not grow well in Bihar.

3. That shaded plants suffer less from die-back and *Choanephora* than unshaded; no conclusions can be drawn regarding the effect of shade on the yield of fruits and percentage of disease.

4. That the application of 2 cwt. superphosphate + 1 cwt. nitrate of soda per acre not only increases the total yield of fruits, but also reduces the percentage of diseased fruits. It is doubtful if the use of artificial manures is possible on account of the present inflated prices of these fertilizers.

5. That two applications of one per cent. Burgundy mixture are enough to control the disease, both on the plants and on the fruits. It is possible that only one application, if given at the right time, may be equally efficacious.

6. That healthy fruits from the sprayed plants remain unspotted on drying, while those from the unsprayed plants develop the disease.

7. That perhaps better results may be got by a combination of application of manure and spraying with Burgundy mixture.

8. That the late sown crop suffers little from die-back and *Choanephora*.

These experiments with a few additions and alterations were repeated in 1918, 1919 and 1920, in order to confirm the results obtained in 1917, but this object was not attained because in these years there was no incidence of this disease, not only at Pusa, but also in the chilli-growing tracts north of the Ganges. It has already been pointed out that high humidity is correlated with the incidence of the disease. These three years, 1918, 1919 and 1920, were comparatively drier and warmer than the previous three years, at the time when the plants are susceptible to infection. Judging from the observations of the last six years it seems that this disease in Bihar becomes virulent when the humidity percentage in the second half of September (when the plants begin to flower) is on an average above 85.

Summary.

The die-back disease of chillies in Bihar, caused by *Vermicularia Capsici* Syd., is described.

The disease first appears in the end of September or in the first half of October when the plants have commenced to flower.

Plants growing in the shade of trees escape the infection.

The late sown crop is also free from this disease.

The infection as a rule commences from the growing point or the flower-bud. The stem dies back as the infection spreads downwards.

The attack on the stem is checked with the first onset of the cold weather.

Infected fruits become spotted when they are ripe, but fruits that mature after the beginning of December are generally free from disease.

Seeds of diseased fruits may become infected. The hyphæ are found not only on the seed coats but also in the inner tissues.

The germination of the infected seed and the development of the seedling depend on the extent of the diseased condition of the seed.

Cultural characters of the fungus are described.

Inoculation experiments show that the plants take the infection only when the humidity is very high. If it is reduced below a certain limit progress of the infection is checked.

From field observations of the last six years it appears that this disease attains great virulence when the humidity percentage is on an average above 85 in the latter half of September.

Control measures tried in 1917 show that Burgundy mixture is useful in checking the disease.

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October 1921 **Botanical Series** **Vol. XI, No. 3.**

Memoirs of the Department of Agriculture in India

THE INFLUENCE OF ATMOSPHERIC CONDITIONS UPON THE GERMINATION OF INDIAN BARLEY

BY

W. YOUNGMAN, B. Sc

Economic Botanist to Government, United Provinces

AGRICULTURAL RESEARCH INSTITUTE, PUSA

PRINTED AND PUBLISHED FOR

THE IMPERIAL DEPARTMENT OF AGRICULTURE IN INDIA

BY

THACKER, SPINK & CO., CALCUTTA
W. THACKER & CO., 2, CREED LANE, LONDON

Price, As. 8 or 1s.

EDITED BY

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October 1921. BOTANICAL SERIES. VOL. XI, No. 6.

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THE INFLUENCE OF ATMOSPHERIC CONDITIONS UPON THE GERMINATION OF INDIAN BARLEY.

BY

W. YOUNGMAN, B. Sc.,

Economic Botanist to Government, United Provinces.

[Received for publication on 14th May, 1921.]

In 1913 attention was called by the Imperial Institute to the fact that whilst Indian barley proved to be quite satisfactory generally for malting purposes in the United Kingdom yet "other shipments contained a large percentage of grains that would not germinate, sometimes amounting to 10 to 20 per cent." The matter was referred to the Department of Agriculture, United Provinces, by the Imperial Institute, and Mr. Wilson, who was then Assistant Economic Botanist, United Provinces, was instructed to carry out an investigation into the matter. Mr. Wilson had collected much information as to methods of storage, and a large number of germination experiments were performed by him when he was transferred to another province. The information and figures collected by Mr. Wilson later passed into my hands. The investigation was again started by me *de novo*, but I wish to acknowledge that the data collected by Mr. Wilson were of considerable assistance to me in my work. The following observations are the result of this work upon the germination of barley carried on through the two seasons 1919 and 1920.

The Imperial Institute reported that it had been noticed that the early shipments of barley generally germinated well and that it was usually the later shipments which exhibited defect.

MAY 10 1922

The quantity of Indian barley exported during the six years 1913–19 is shown in the following table :—

TABLE I.*

Quantity and value of barley exported during six years with the share of the different ports.

Ports		1913–14	1914–15	1915–16	1916–17	1917–18	1918–19
		Tons	Tons	Tons	Tons	Tons	Tons
Karachi		127,622	28,865	159,533	172,034	347,747	215,305
Calcutta		54,249	54	74	1,478	97	43
Bombay		8,519	394	6,147	35,929	10,787	10,999
Rangoon		10	4	3	5	91	4
TOTAL	Quantity	190,400	29,317	165,757	209,446	358,722	226,351
	Value £	1,043,799	174,548	1,168,003	1,509,615	2,693,512	1,845,111

---

* This statement is taken from the "Handbook of Commercial Information for India," by C. W. E. Cotton, 1919.

Export figures obtained from the Director of Statistics with the Government of India showed the exports of barley by sea to foreign countries month by month for the year 1913-14 to be as under :—

TABLE II.

Quantity of barley exported by sea from each maritime province of British India to foreign countries in each month of the official year 1913-14.

Months	Bengal	Bombay	Sind	Madras	Burma	Total
1913	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.
April	12,864	18,885	9,682	..	54	41,485
May	101,758	4,176	236,862	..	12	342,808
June	276,564	12,782	199,919	..	30	489,295
July	201,569	46,167	819,373	..	..	1,067,109
August	228,761	40,293	526,415	..	..	795,469
September	125,265	28,009	309,454	..	..	462,728
October	44,153	14,134	197,432	..	..	255,719
November	85,851	2,644	146,055	..	..	234,550
December	8,034	1,456	17,599	..	..	27,089
1914						
January	30	1,438	60,254	..	34	61,756
February	108	82	3,444	..	10	3,644
March	40	318	25,946	..	50	26,354
TOTAL	1,084,997	170,384	2,552,435	..	190	3,808,006

The year 1913-14 is perhaps the fairest average year to take for indication as to the movement of the grain for two reasons—it represents a year uninfluenced by war, and we may assume that the barley was more likely to be wanted for malting purposes then than in later years when there were restrictions as to brewing and greater demand for barley for both human and cattle food. For the latter purpose be the germination bad or good it is immaterial.

The statistics show plainly that much the greatest amount is exported in the month of July. Indeed in this month alone normally some one-third of the total yearly export leaves our Indian ports. This is no doubt the climax of an attempt on the part of the exporter to avoid the monsoon.

Practically the whole of the exports go to the United Kingdom. Particular attention may be called to the large amount that is moved toward Calcutta (Bengal. in Table II) for export in the months of June, July, August, and September. As we shall show later, the region of Bengal and the Bay of Bengal during these months is a danger zone for barley. Barley subjected for some 3–4 weeks to the conditions prevailing in this region is bound to have its germination percentage considerably reduced.

The explanation of the poor germination suggested by the Referees on cereals to the Imperial Institute was that it seemed possible that the injury to the barley happened to that which failed to get railed and shipped before the monsoon set in a d consequently was stored in the cultivators' pits and huts, the serious effect being due to the humidity and warmth of the rainy season followed by a subsequent drying before the barley reached England. It was thought that the grain situated close to the wall of the pit suffered whilst that in the centre escaped. Subsequent experiment, as we shall show, demonstrates the effect to be due to the humidity, but there are other points of interest not suspected previously. The 10–20 per cent. that fails to germinate though is probably not due to its being the amount that is situated on the outside of the store. Observation makes us think that it is very doubtful whether any portion of the exported barley has ever been stored in any efficient way in the grain dealer's storehouse. The methods usually employed afford little or no protection from atmospheric conditions. The cultivator as a rule stores only the grain required for food and seed purposes and sells off his surplus stock at harvest time.

The small quantities of grain retained by the cultivators for seed and domestic use are usually stored in mud urns. In North-East India the cultivator's seed rate for barley as for many other crops is known to be high.

The reason is obvious. The whole subject of the germinating value of the seed usually sown by cultivators for their crops is worth further study.

A sample of barley was taken in June before the rains set in, and from this a number of small cotton bags were lightly filled with some 1,000 kernels each. Some of these bags were stored in a closed large dessicator, beneath the perforated zinc floor of which was about a pound of anhydrous calcium chloride. By this means the influence of the weather was removed and the seed kept until its regular germinating season. These bags of grain simply served as a control. They were used during barley-sowing season when a check experiment was deemed necessary. The germination of our barley was found to be uniformly high, samples from this dessicator often showing 99 per cent. and never below 96 per cent. germination. Others of these bags of grain were exposed for various intervals of time to atmospheres containing different amounts of water vapour. At the termination of these exposures the bags were transferred to a second large dessicator containing calcium chloride and remained there until barley-sowing season in November. At this season the germination of the barley subjected to various degrees of moist atmosphere for various durations of time was tested in each case.

The experimental method was as follows. In order to obtain atmospheres containing different amounts of moisture a number of small dessicators of approximately uniform size were taken. Into successive dessicators were put 200 c.c. of successively stronger solutions of sulphuric acid. (The sulphuric acid used was an ordinary commercial sample. The same sample of acid was used throughout the experiment. Its exact degree of strength and purity was unimportant as the technique of the experiment will show.) A start was made with pure water in small dessicator No. 1, and 2 per cent. sulphuric acid in No. 2, 4 per cent. in No. 3 and so on; there being an increment of 2 per cent. acid in the solution in each succeeding dessicator. Upon the perforated floors of the dessicators, over the acid, the small bags of barley were placed. The glass top of the dessicator was then hermetically sealed by means of a lute of resin cerate. After an interval of one week one bag was removed from each small dessicator. These bags were marked so as to show the strength of acid and duration to which they had been exposed. They were then transferred to a large storage dessicator in the bottom of which was a quantity of anhydrous calcium chloride. From this dessicator the bags were taken out as fast as they could be dealt with and the germination of the grains in the various bags tested. After a further interval of a week a second bag of barley was removed from each small dessicator, labelled, and transferred to the large dessicator to await its turn for a germination experiment of its contents.

This removal of bags from the small dessicators continued at weekly intervals. The germination tests were carried out as follows. The method is the one recommended by Schönfeld in *Wochensch Brau*, 1902, **19**, 768. A wooden stand containing a line of small glass funnels was fitted up. In the apex of each funnel a small plug of glass wool was placed. A short length of india-rubber tubing provided with a pinch cock was attached to the stem of each funnel. The barley was placed on the glass wool and then flooded with water for about five hours. The water was then run off by opening the pinch cock and the barley left alone for some 18–19 hours. At the end of this time the barley was again flooded for a second period of five hours. Two floodings were sufficient to start germination, and, with but few exceptions, all those grains that would germinate did so by the third day, very few lingered until the fourth, on which day the germinated grains were counted. The funnels were kept covered during the experiment with clock glasses. Observations of the maximum and minimum temperatures of the laboratory were made daily. The percentages of germinating grains are given in the table below. A set of estimations of the amounts of water vapour contained in samples of air exposed to solutions of sulphuric acid of the strengths used was then made. This was carried out in the following manner :—

A series of four small wash bottles was fitted up and into each was put a quantity of sulphuric acid of the percentage under consideration. The intake tube of one bottle was connected with the exit tube of the bottle before it, and the intake tube dipped beneath the surface of the acid in its bottle. Air was drawn slowly through this series of four bottles containing the sulphuric acid. Connected to the fourth bottle was a U tube containing calcium chloride. This calcium chloride tube was in its turn connected to a second one, and this again to a third calcium chloride tube which was followed by an empty U tube. Through all these tubes and bottles a measured quantity of air was drawn by means of an aspirator of 20,000 c.c. capacity. The air was drawn over very slowly, the whole 20,000 c.c. taking some five hours. The two calcium chloride tubes next the bottles containing the acid were weighed before and after the experiment. The third calcium chloride and the empty U tube also were simply to catch any water vapour passing back from the aspirator ; they were not weighed. By this means we were able to estimate the number of grams of water vapour per litre contained in air over each particular percentage sample of sulphuric acid used. The following table gives the results :—

TABLE III.

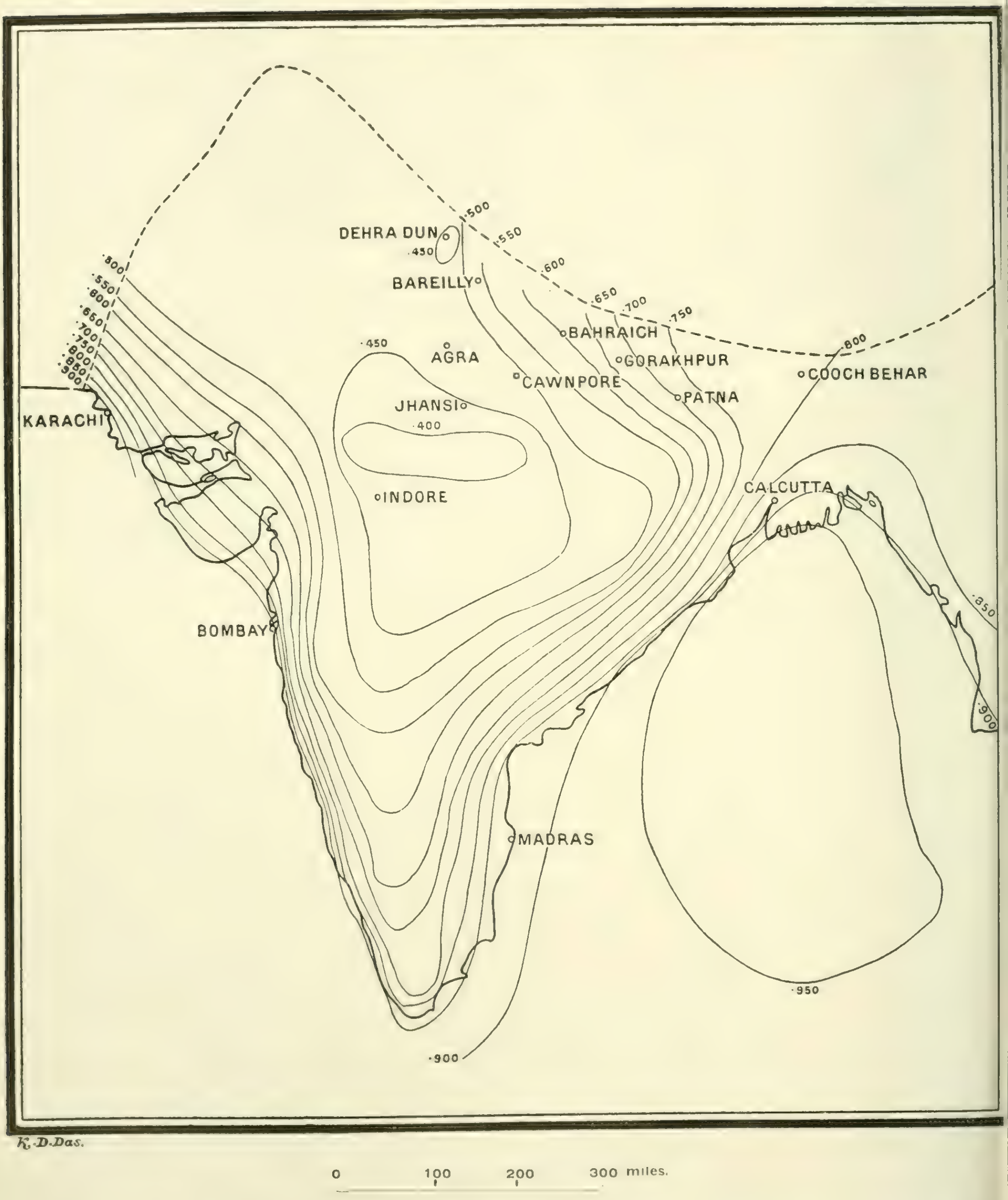
Germination tests with barley.

The germination tests were commenced on the 10th November and during the experiments the laboratory temperature at 8 A.M. was a maximum of 28°C. and a minimum of 18°C.

Percentage of H_2SO_4 used	Grm. water vapour per litre contained in air over this percentage of H_2SO_4 (as estimated by us)	T. of laboratory in which column 2 was estimated	Vapour pressure in inches of column 2 figures	PERCENTAGE OF GERMINATING GRAINS AFTER EXPOSURES OF DIFFERENT DURATIONS													
				1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks	11 weeks	12 weeks	13 weeks	14 weeks
		°C.															
0 (*i.e.*, water)	*0·0307	31	1·3″	97·2	98·8	96·6	91·3	86·9	87·1	88·7	15·0	4·3	2·0	0·1	0	..	..
2	0·0264	23	1·1″	99·1	98·7	97·1	94·4	91·6	84·6	79·1	60·3	49·3	27·2	7·2	0	..	..
4	0·0233	30	0·96″	96·6	98·6	98·7	87·5	83·6	85·8	75·1	63·5	49·1	33·5	22·8	8·4	0	..
6	0·0223	30	0·92″	97·2	98·3	98·4	96·3	96·3	98·3	78·5	55·5	71·8	43·6	33·7	9·7	2·9	0
8	0·0216	30·5	0·89″	99·0	96·7	99·0	84·2	97·5	95·6	95·3	90·3	86·3	86·5	78·7	74·8	70·2	76·5
10	0·0213	30·5	0·87″	97·6	98·4	99·3	97·8	98·5	96·6	98·3	96·0	96·5	97·2	94·2	93·7	95·0	96·3
12	0·0199	30·5	0·82″	98·5	98·5	98·6	97·0	98·8	98·7	98·4	97·2	96·2	98·2	96·9	98·7	98·3	98·5

*This is the figure obtained by us. 0·0300 grm. is the weight of water vapour in 1 litre of saturated air at 760 mm. pressure and 30°C. By comparison with our figure an estimate can be formed as to the experimental error in our method.

The vapour pressure, p, in inches given in column 4, is found by the formula $p = W \times 37 \cdot 5 \times \frac{T+273}{273}$ where W = no. of grams of vapour in a litre of air. T = temperature of air in °C. and where air is at sea level under standard pressure of 29·92 inches.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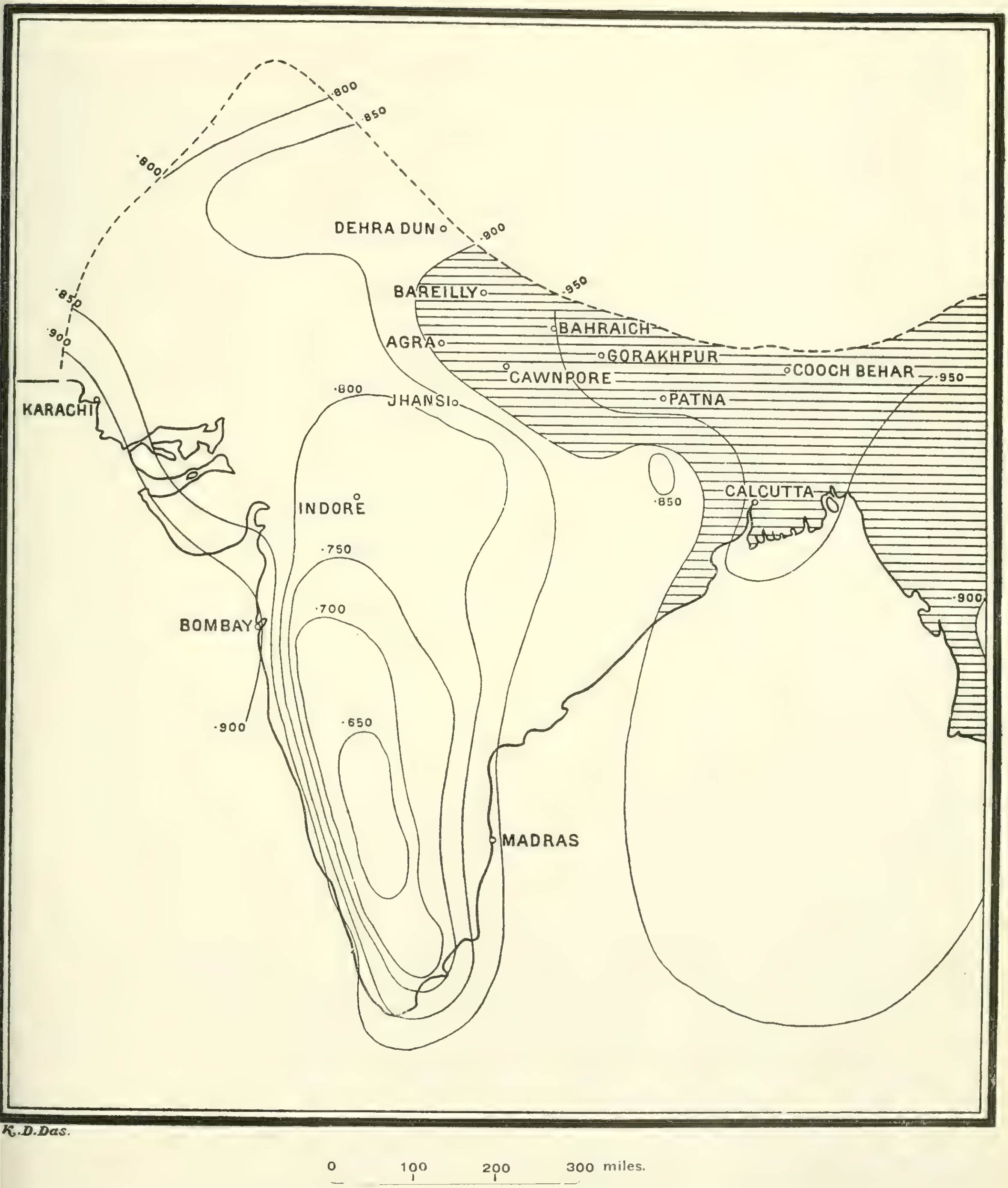
·700
·750
·800
BAHRAICH
·450
AGRA
GORAKHPUR
CAWNPORE
COOCH BEHAR
PATNA
JHANSI
KARACHI
·400
INDORE
CALCUTTA
BOMBAY
·850
·900
MADRAS
·950
·900
K.D.Das.
0
100
200
300 miles.

May. Mean daily aqueous vapour pressure. Taking 0·900″ aqueous vapour as the danger line for barley it will be seen that at this season there is hardly any inland danger zone.


·800
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BAHRAICH
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CAWNPORE
COOCH BEHAR
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JHANSI
PATNA
INDORE
·850
CALCUTTA
·750
·700
·900
BOMBAY
·900
·650
MADRAS
0
100
200
300 miles.

K.D.Das.

July. Mean daily aqueous vapour pressure. The shaded area represents the inland danger zone for barley. This persists somewhat similarly for some 12 to 14 weeks in the year,

From Table III given above it will be seen that a vapour pressure of 0·87″ (0·0213 grm. water vapour per litre of air) may be taken as the safest maximum to which Indian barley intended for germination may be exposed. Exposure to this amount of humidity for fourteen weeks has no deleterious effect. Exposure to greater amounts of humidity than this is serious. A vapour pressure of 0·89″ (=0·0216 grm. water per litre of air) after fourteen weeks or less reduces the germination by roughly some 25 per cent. and greater humidity than this totally destroys germinating power in fourteen weeks or less.

Comparisons between Table III and the maps showing the aqueous vapour pressures inland for the months of May and July are instructive. A series of these maps for each month of the year is to be found in the "Climatological Atlas of India." For fuller details a reference to them may be made. In short it may be said that conditions in June are intermediate between May and July and that July conditions represent somewhat those of August and September. October to April rarely shows vapour pressures above 0·85″ anywhere, not even on the seaboard. After May barley in North-Eastern India is to be regarded as having been subjected to atmospheric conditions that have a deleterious effect upon its germination. Unless extraordinary storage precautions be taken barley in this region during the period of the monsoon will have its germination reduced by anything up to some 25 per cent. Thus we see where and why the cultivator's seed rate is high. Barley required for malting purposes (or any other use involving its germination) should not be that exported from Calcutta after May. Bengal, Bihar and Orissa, and Oudh produce the barley exported from Calcutta. Its germination could, if necessary, be fully protected by transporting it from the danger zone toward Karachi or Bombay before, say, the end of June. This would involve some extra cost for increased railway transport. It should not be stored on the Western seaboard area. Barley in North-West and Central India has its germination unimpaired throughout the year and if exported from Bombay or Karachi, and not delayed long in the seaboard area, will not have suffered from the effects of harmful atmospheric conditions. It might be supposed that humidity conditions over the ocean which the grain would encounter during seaborne transport to Europe are above the safety maximum. They may be, but on a normal voyage they are not likely to last sufficiently long to have a serious effect.

In conclusion, I wish to acknowledge the assistance received from Mr. A. Wilson, of the Indian Agricultural Service ; The Director of Statistics, India ; and The Director-General of Observatories, Indian Meteorological Department.

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[Received for publication on 10th June, 1921.]

In the account given below, the inheritance of the following characters in the rice plant is discussed.

(1) Colour characters due to soluble pigment occurring in various parts of the growing plant.
(2) Colour of the mature kernel, *i.e.*, the husked grain.
(3) Colour of the mature inner glumes, *i.e.*, the husk.

Most of the above characters have been found to give definite Mendelian ratios, and many have been proved to be inherited in groups or patterns and not independently. It is mainly from the latter point of view that they are described in the present paper.

The characters noted above will be taken up in order.

Colour characters due to dissolved pigment.

A large number of varieties of rice are characterized by the presence of coloured pigment distributed throughout various parts of the plant, but the majority of varieties are devoid of colour and are wholly green during the vegetative period. The colour is due to soluble pigment dissolved in the cell sap. This colour can be made a basis for classification into (1) coloured varieties and (2) green or colourless.

The colours concerned range from reds through blues to deep purple ; the difference in colour being generally due simply to the degree of concentration, but in certain cases apparently to their being in themselves intrinsically different.

The chief situations of this colour are :—

(1) The leaf-sheath, pulvinus of leaf, ligule and auricles.
(2) The internode.
(3) The small outer glumes.
(4) Apiculus of the inner glumes.
(5) The inner glumes as distinct from the apiculus.
(6) The stigma.

The above will be readily understood by a reference to the plate.

The varieties so far studied at Dacca with reference to the distribution of these colours may be broadly grouped as follows :—

(1) Varieties with leaf-sheaths, apiculus of glumes and stigma coloured.
(2) Leaf-sheaths and apiculus of glumes coloured, but stigma colourless (white).
(3) Apiculus of glumes only coloured.

Each of these groups may have colour in other parts also, such as the nodes, internodes, outer glumes and body of inner glumes as distinct from the small spot of colour at the apex, the so-called apiculus. Indeed the colour is found in so many combinations, each breeding true in pure-line cultures, that any satisfactory grouping is not possible. Types can only be described. Moreover, varieties which outwardly appear similar in colour characters may be found on investigation to have the colour situated in different parts of the cell-anatomy ; as, for example, in the internode and leaf-sheath, where varieties which outwardly appear the same may have the colour situated in the epidermal layer only, or in the bundle sheaths only, or in both together.

Early results,[1] obtained chiefly from the analysis of the offspring of natural crosses, showed that these colours were frequently due to the interaction of several factors, and that they were often combined into patterns which were inherited as a whole. In order to investigate the mode of inheritance of these colour patterns more thoroughly, a series of crosses were made between a number of variously coloured paddies and green varieties, and the data discussed below have all been derived from the results of these experiments. In the first place, the inheritance of colour in each of the various situations referred to will be described without reference to the others. The combinations of the colour characters will be discussed later.

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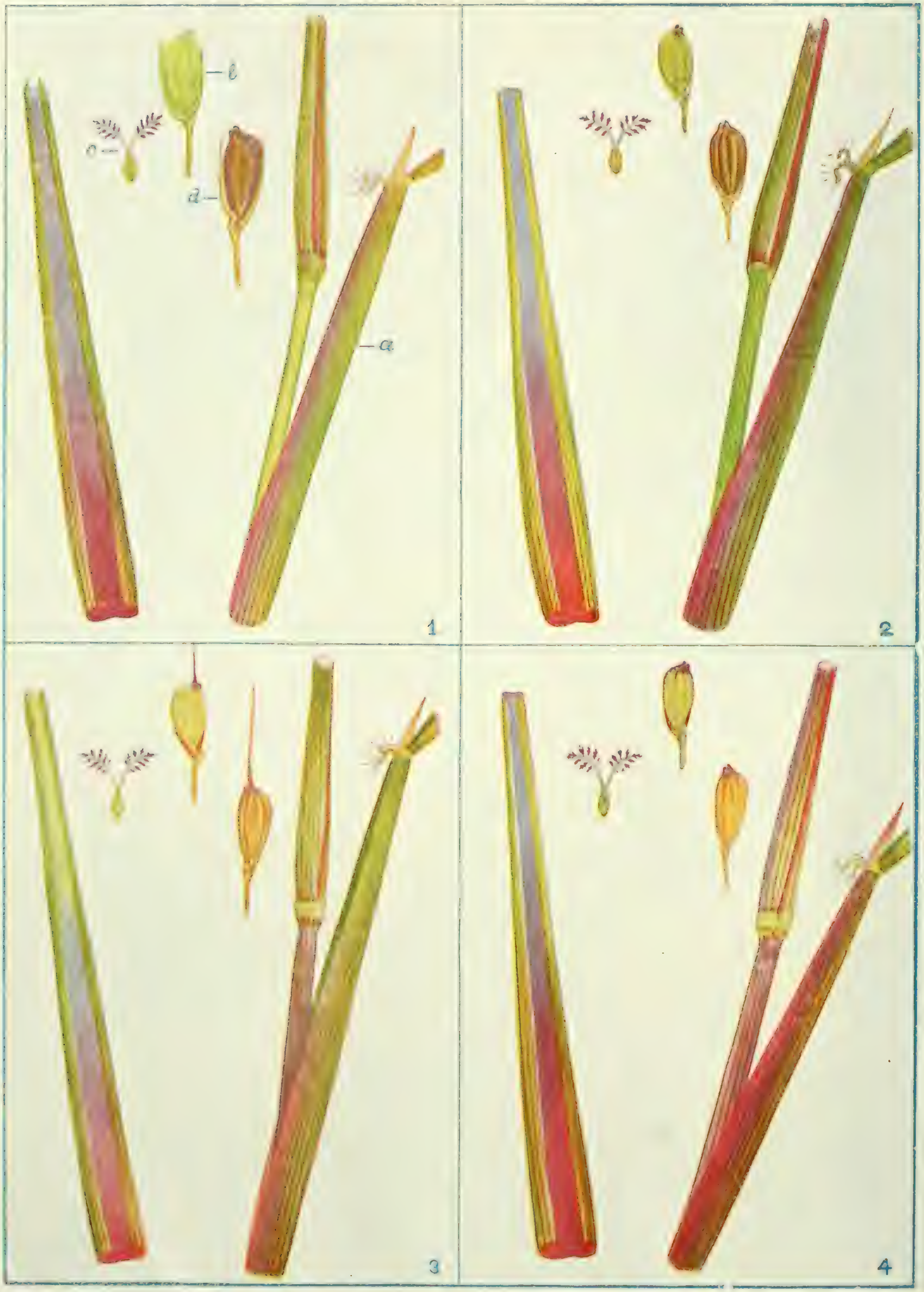
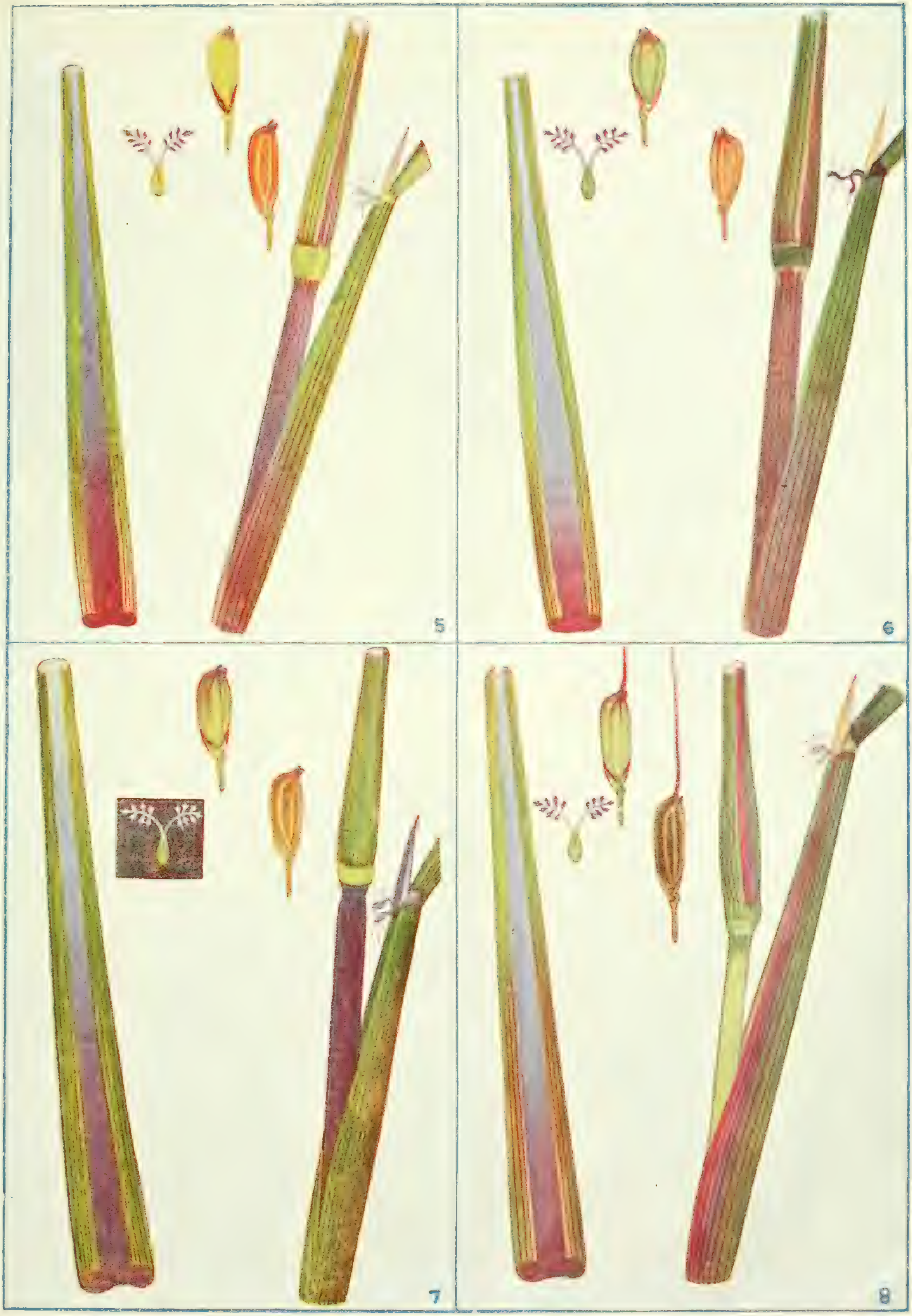
[1] Hector, G. P. "Observations on the Inheritance of Anthocyan Pigment in Paddy Varieties." *Mem. Dept. Agri. India, Bot. Ser.*, VIII, no. 2, Nov. 1916.



1, PANKHIRAJ; 2, MATICHAK; 3, NOACHUR; 4, MURAMAGAR:



5. SURJAMUKHI; 6. BAILABAKRI; 7. AGARTOLLAH; 8. CHITTAGONG.

COLOUR IN THE LEAF-SHEATH.

The development of colour varies greatly. It is generally developed mainly in the epidermis and underlying layers of the inside of the leaf-sheath, in the epidermis and adjacent layers of the outside of the leaf-sheath, in the tissues surrounding the bundles (bundle-sheaths), and may also occur scattered in the general parenchyma. Frequently, on the outside of the leaf-sheath it is found only in the epidermal layer towards the margin, thus producing the conspicuous red line seen in some varieties running down the overlapping edge of the sheath. These different colour situations may be due to different factors, but in our experiments, coloured leaf-sheath means simply the presence of colour of any sort visible from the outside to the naked eye. This colour in the leaf-sheath has always been found dominant to its absence, and to segregate in F_2 in a simple 3 : 1 ratio, a 9 : 7 ratio, a 27 : 37 ratio, and in a 15 : 1 ratio. Thus the colour is due either to a simple factor or to two or more interacting factors.

The table gives details of crosses in which these various ratios have been obtained :—

Theoretical ratio	Variety Colour × no colour	F_2 Colour : no colour	Observed ratio Colour : no colour
3 : 1	Pankhiraj × Pookhi	Total 5 families 1,015 : 317	3·2 : 1
	Surjamukhi × Pookhi	One family 731 : 261	2·8 : 1
	Muramagar × Pookhi	Total 4 families 2,198 : 818	2·6 : 1
	Matichak × Pookhi	Total 9 families 2,703 : 829	3·2 : 1
	Bailabakri × Pookhi	Total 7 families 3,485 : 1,202	2·8 : 1
9 : 7 (1·2 : 1)	Agartollah × C 25	Total 4 families 2,670 : 1,999	1·3 : 1
27 : 37 (1 : 1·3)	C 9 × C 25	Total 2 families 644 : 686	1 : 1·06
15 : 1	Noachur × Pookhi	Total 3 families 1,129 : 70	16·1 : 1

2. COLOUR IN THE LIGULE.

In two varieties out of those experimented with, the ligule is coloured. In the first, the colour segregates in a 9 : 7 ratio, in the second in a 27 : 37 ratio. The details are given in the table.

Theoretical ratio	Variety Colour × no colour	F_2 Colour : no colour	Observed ratio Colour : no colour
9 : 7 (1·2 : 1)	Muramagar × Pookhi	Total 4 families 1,646 : 1,370	1·20 : 1
27 : 37 (1 : 1·3)	Agartollah × C 25	Total 8 families 1,972 : 2,697	1 : 1·36

3. COLOUR IN THE PULVINUS AND AURICLES.

In two varieties experimented with, colour is found in the pulvinus and auricles, *viz.*, in the variety Bailabakri and in the variety Agartollah. These both segregate in a 9 : 7 ratio as shown in the table.

Theoretical ratio	Variety Colour × no colour	F_2 Colour : no colour	Observed ratio Colour : no colour
9 : 7 (1·2 : 1)	Bailabakri × Pookhi	Total 8 families 2,607 : 2,080	1·2 : 1
	Agartollah × C 25	Total 7 families 2,670 : 1,999	1·3 : 1

4. COLOUR IN THE INTERNODE.

As in the leaf-sheath, colour in the internode is found in the epidermis, in the bundle-sheaths, in the general parenchyma, or in various combinations of these. Here again coloured internode means simply visible colour in the internode, as seen from the outside by the naked eye, irrespective of the situation of the colour. Colour has always been found dominant to its absence, and on crossing, has been found, in the varieties experimented with, to segregate in a 3 : 1 ratio, a 9 : 7 ratio and a 27 : 37 ratio. The results are given in the table :—

Theoretical ratio	Variety Colour × no colour	F_2 Colour : no colour	Observed ratio Colour : no colour
3 : 1	Surjamukhi × Pookhi	Total 1 family 731 : 261	2·8 : 1
	Noachur × Pookhi	Total 3 families 867 : 332	2·6 : 1
	Muramagar × Pookhi	Total 4 families 2,198 : 818	2·6 : 1
	Bailabakri × Pookhi	Total 7 families 3,461 : 1,226	2·7 : 1
9 : 7 (1·2 : 1)	Agartollah × C 25	Total 8 families 2,670 : 1,999	1·3 : 1
27 : 37 (1 : 1·3)	C 16 × C 25	Total 2 families 468 : 634	1 : 1·3

5. Colour in outer glumes.

Simple 3 : 1 segregation, as well as 9 : 7 segregation has been found, as shown in the table.

Theoretical ratio	Variety Colour × no colour	F_2 Colour : no colour	Observed ratio Colour : no colour
3 : 1	Surjamukhi × Pookhi	Total 1 family 750 : 242	3·0 : 1
	Noachur × Pookhi	Total 3 families 907 : 292	3·1 : 1
	Bailabakri × Pookhi	Total 7 families 3,571 : 1,116	3·1 : 1
9 : 7 (1·2 : 1)	Muramagar × Pookhi	Total 4 families 1,647 : 1,369	1·2 : 1
	Agartollah × C 25	Total 8 families 2,671 : 1,998	1·3 : 1

6. COLOUR IN THE INNER GLUMES.

In many varieties with colour in the outer glumes, colour is also found in the inner glumes, apart from the spot of colour at the apex, the apiculus. This applies to all the varieties experimented with, all with colour in the outer glumes having the inner glumes also tinged with colour, and the two characters have been found to segregate together. Thus the table above applies also to the inner glumes.

7. COLOUR IN THE APICULUS.

The apiculus or apex of the inner glumes is coloured in a large number of varieties. The colour consists of a spot at the extreme tip. As in other localizations, colour in the apiculus has been found to be due either to a single factor or to two or more interacting factors. Actual results obtained are given in the table.

Theoretical ratio	Variety Colour × no colour	F_2 Colour : no colour	Observed ratio Colour : no colour
3 : 1	Pankhiraj × Pookhi	Total 5 families 1,015 : 317	3·2 : 1
	Muramagar × Pookhi	Total 4 families 2,198 : 818	2·6 : 1
	Matichak × Pookhi	Total 9 families 2,714 : 818	3·3 : 1
9 : 7 (1·2 : 1)	Agartollah × C 25	2,671 : 1,998	1·3 : 1
27 : 37 (1 : 1·3)	C 9 × C 25	Total 2 families 644 : 686	1 : 1·06
15 : 1	Surjamukhi × Pookhi	Total 1 family 946 : 46	20·5 : 1
	Noachur × Pookhi	Total 3 families 1,131 : 68	16·1 : 1
	Bailabakri × Pookhi	Total 7 families 4,390 : 297	14·7 : 1

8. COLOUR IN THE STIGMA.

A coloured stigma is found in a large number of varieties. The colour varies in intensity from a pale red to a deep purple. It has been found to be due to a simple factor or to several interacting factors, as shown in the table :—

Theoretical ratio	Variety Colour × no colour	F_2 Colour : no colour	Observed ratio Colour : no colour
3 : 1	Pankhiraj × Pookhi	Total 5 families 1,015 : 317	3·2 : 1
	Surjamukhi × Pookhi	Total 1 family 731 : 261	2·8 : 1
	Noachur × Pookhi	Total 3 families 870 : 329	2·6 : 1
	Muramagar × Pookhi	Total 4 families 2,198 : 818	2·6 : 1
	Matichak × Pookhi	Total 9 families 2,703 : 829	3·2 : 1
	Bailabakri × Pookhi	Total 7 families 3,485 : 1,202	2·8 : 1
27 : 37 (1 : 1·3)	C 16 × C 25	Total 2 families 471 : 631	1 : 1·3
81 : 175 (1 : 2·1)	C 9 × C 25	Total 2 families 469 : 861	1 : 1·8

SUMMARY.

In our experiments the colour in these different situations has been found to be due to a simple factor, segregating 3 : 1 in F_2, or to two, three, and in one case to four interacting factors, giving ratios of 9 : 7, 27 : 37, 81 : 175 and 15 : 1. Moreover, the genetic constitution of a colour character in any one type is no index of its constitution in another type, the same character having in different types been found to give most of the above ratios.

The combination of colour characters.

Hitherto we have dealt with the inheritance of these colour characters independently of each other. It is, however, when we consider them in relation to each other, that most interest attaches to them. We give in the Appendix (I) a table showing the various combinations of colour characters which have been found in 211 varieties critically examined. On examination, it is found that certain combinations occur more frequently than others, while on the other hand certain combinations are never found. The most frequent combination is that of the leaf-sheath and apiculus of the inner glumes. This combination occurs together in 162 varieties out of the 211 examined. The next most common combinations are the leaf-sheath, internode and apiculus which are found together in 154 varieties, and the leaf-sheath, apiculus and stigma occurring together 98 times. Conversely, it is to be noted that certain combinations are absent, *e.g.*, colour in the leaf-sheath and stigma is never found without colour in the apiculus, though the apiculus may be coloured without colour in the leaf-sheath or stigma. It is therefore to be expected that, on crossing with colourless varieties, these combinations will ordinarily be found to stick together as patterns, while, conversely, other combinations, which should be found if independent segregation is taking place, will be lacking. This has been found to be the case.

In the experiments detailed below, the following combinations have been worked with (*cf.* Appendix II) :—

1. Variety Pankhiraj—coloured* leaf-sheath, coloured apiculus, coloured stigma (Fig. 1).
2. Variety Matichak—coloured leaf-sheath, coloured apiculus, coloured stigma (Fig. 2).
3. Variety Noachur—coloured leaf-sheath, internode, outer glumes, inner glumes, apiculus, stigma (Fig. 3).
4. Variety Muramagar—coloured leaf-sheath, ligule, internode, outer glumes, inner glumes, apiculus, stigma (Fig. 4).
5. Variety Surjamukhi—coloured leaf-sheath, internode, outer glumes, inner glumes, apiculus, stigma (Fig. 5).
6. Variety Bailabakri—coloured leaf-sheath, internode, pulvinus and auricle, outer glumes, inner glumes, apiculus, stigma (Fig. 6).
7. Agartollah—coloured leaf-sheath, internode, pulvinus and auricles, ligule, outer glumes, inner glumes, apiculus (Fig. 7).

The first six have in each case been crossed with a wholly green variety, Pookhi, while the seventh has been crossed with a green variety, C 25, and pure-line material has been used throughout. These crosses will be described in order.

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* In the descriptions the word "coloured" only is used, but the colours themselves vary, and the exact shade of colour can be seen by a reference to the plate.

1. Variety Pankhiraj × Variety Pookhi. The system "coloured leaf-sheath, apiculus, stigma" has been found to stick together absolutely, giving 3 coloured plants : 1 green plant in F_2, the total of 5 families giving 3·2 coloured : 1 green (*cf.* tables above and Appendix II).

2. Variety Matichak × Var. Pookhi. The same combination behaves the same way as in No. 1, the total of nine families giving 3·2 coloured : 1 green.

3. Variety Noachur × Var. Pookhi.

(A) The system "leaf-sheath and apiculus" sticks together (2 exceptions were found out of 1,199 plants, *viz.*, two plants with coloured apiculus but green leaf-sheath) and segregates 15 coloured : 1 green in F_2 (total of 3 families gave 16·1 coloured : 1 green).

(B) The system "internode and stigma" sticks together (3 exceptions were found out of 1,199 plants, *viz.*, three plants with coloured stigma and green internode) segregating 3 coloured : 1 green (total three families gave 2·6 : 1).

(C) The colour in the outer and inner glumes gives 3 coloured : 1 green (total of three families gave 3·1 : 1).

In this variety there are thus three systems: (1) "leaf-sheath and apiculus" (2) "internode and stigma" (3) "outer and inner glumes." We shall call these A, B, C and treat each in relation to the other two.

I. A and B. A alone segregates 15 : 1, B alone segregates 3 : 1. On crossing with a colourless type (ab), we should therefore get, if A and B are due to different factors segregating independently of each other–

15 A : 1 a
3 B : 1 b

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45 AB : 3 aB : 15 Ab : 1 ab.

Actually observed, 870 AB : O aB : 261 Ab : 68 ab (3 families of 1,199 plants).

The class aB (*i.e.*, the combination of "green leaf-sheath and apiculus" with "coloured internode and stigma") is absent.

This result can be brought about if system B (internode and stigma) is due to a single factor, and system A (leaf-sheath and apiculus) is due to two factors, *viz.*, to the factor responsible for B, together with a further factor, interacting with the factor responsible for B in such a way that both or either produces colour. This is the same as saying that one factor is common to both, or that, if there are two factors, they must be completely inked. We get thus—

$$\begin{array}{ccccccc} \multicolumn{5}{c}{15\,A} & : & 1\,a \\ \multicolumn{5}{c}{\overbrace{\hphantom{AB : aB : Ab}}} & & \\ AB & : & aB & : & Ab & : & ab \\ 9 & : & 3 & : & 3 & : & 1 \\ \multicolumn{3}{c}{\underbrace{\hphantom{AB : aB}}} & & \multicolumn{3}{c}{\underbrace{\hphantom{Ab : ab}}} \\ \multicolumn{3}{c}{12B} & & \multicolumn{3}{c}{4\,b} \end{array}$$

or	..	12AB	:	0 aB	:	3 Ab	:	1 ab	
Observed	..	870	:	0	:	261	:	68	(3 families of 1,199 plants)
Expect	..	899·04	:	0	:	224·76	:	74·92	

The above is a common mode of segregation, occurring frequently in many varieties. It is to be noted that the combination which is wanting is one which does not occur in the 211 varieties examined (*cf.* Appendix I).

II. A and C. The case is exactly comparable to I, system A segregating 15 : 1, system C, 3 : 1

		AC		aC		Ac		ac	
Observed	..	907	:	0	:	224	:	68	(1,199 plants, 3 families)
Expect	..	899·16	:	0	:	224·79	:	74·93	
Ratio	..	12	:	0	:	3	:	1	

Again the combination wanting, *viz.*, "green leaf-sheath and apiculus" (*a*) with "coloured outer glumes" (C), is not found in the 211 varieties examined.

III. B and C Both segregate 3 : 1. We therefore expect, if independent segregation is taking place—

		BC		Bc		bC		bc	
		9	:	3	:	3	:	1	
Observed	..	648	:	222	:	259	:	70	(1,199 plants, 3 families)
Expect	..	674·37	:	224·79	:	224·79	:	74·93	

Segregation is independent and all combinations occur in their expected ratios.

4. Variety Muramagar × Var. Pookhi.

(A) The system "leaf-sheath, internode, apiculus and stigma" sticks together absolutely, giving 3 coloured : 1 colourless (total 4 families, 2·6 : 1).

(B) The colour in the ligule segregates 9 coloured : 7 colourless (total 4 families, 1·2 : 1).

(C) The colour in the outer and inner glumes gives 9 coloured : 7 colourless (total 4 families, 1·2 : 1).

I. A and B. A segregates 3 : 1, B 9 : 7. If A and B are due to separate factors, segregating independently, we should get—

	A 3	:	1 a		
	B 9	:	7 b		
	27 AB	:	9 aB :	21 Ab :	7 ab
Actually observed ..	1,646	:	0 :	552 :	818 (4 families of 3,016 plants)

The combination of "green leaf-sheath, internode, apiculus, and stigma" (*a*) with "coloured ligule" (B) does not occur.

This again can be brought about if system A is due to a single factor, and system B to the same factor, together with a second factor interacting with the factor responsible for A in such a way that the presence of both is necessary for the production of colour. Thus again one factor is common to both, or the two factors must be completely linked. We thus get—

	12 A			4 a		
	AB	:	Ab :	aB :	ab	
	9	:	3 :	3 :	1	
	9B	:		7b		
or ..	9AB	:	3Ab :	0 aB :	4 ab	
Observed ..	1,646	:	552 :	0 :	818	(4 families of 3,016 plants)
Expect ..	1,696·5	:	565·5 :	0 :	754	

II. A and C. A segregates 3 : 1, C 9 : 7. This case is exactly comparable to the former—

	12 A			4 a		
	AC	:	Ac :	aC :	ac	
	9	:	3 :	3 :	1	
	9C	:		7c		
or ..	9 AC	:	3 Ac :	0 aC :	4 ac	
Observed ..	1,647	:	551 :	0 :	818	(4 families of 3,016 plants)
Expect ..	1,696·5	:	565·5 :	0 :	754	

The combination of "green leaf-sheath, internode, apiculus and stigma" (a) with "coloured outer glumes" (C) does not occur.

III. B and C. B segregates 9 : 7, C 9 : 7, so if segregating independently the expected ratio is—

	9 B	: 7 b			
	9 C	: 7 c			
	81 BC	: 63 Bc	: 63 bC	: 49 bc	
Observed ..	1,253	: 393	: 394	: 976	(4 families of 3,016 plants)
Expect ..	954·3	: 742·21	: 742·21	: 577·27	

Here the expected combinations are all present, though not in the expected ratios. There are too many of the parental types, BC and bc, and too few of the cross-over types. The actual ratios obtained in the four different families were as follows :—

	BC	: Bc	: bC	: bc
1. ..	92	: 36	: 27	: 90
2. ..	196	: 58	: 48	: 118
3. ..	834	: 266	: 296	: 714
4. ..	131	: 33	: 23	: 54
TOTAL ..	1,253	: 393	: 394	: 976

The figures are somewhat irregular, but on examination some of the ratios obtained are found to be a fairly close approximation to expectation on a basis of a 7 : 1 coupling of the parental gametes. On this basis the expected ratios are—

1. ..	122·81	· 30·93	: 30·93	: 60·33
2. ..	210·53	: 53·14	: 53·14	: 103·39
3. ..	1057·69	: 266·44	: 266·44	: 519·42
4. ..	120·80	: 30·44	: 30·44	: 59·32

To definitely prove the gametic constitution of the F_1, it would be necessary to backcross it with the recessive parent, a very laborious undertaking in the case of a cereal like rice, as each cross results only in the production of one fertilized seed, and to obtain only 100 plants would require 100 crossings, and that assuming all were successful and all seeds germinated and reached maturity.

5. Variety Surjamukhi × Variety Pookhi.

(A) The combination "leaf-sheath, internode and stigma" sticks together absolutely, giving 3 coloured : 1 colourless (992 plants gave 2·8 : 1).

(B) Colour in outer and inner glumes gives 3 coloured : 1 colourless (992 plants gave 3 : 1).

(C) Colour in the apiculus gives 15 : 1 (992 plants gave 20 : 1).

I. A and B. A segregates 3 : 1, B 3 : 1. If independent segregation takes place, we expect—

		9 AB	3 Ab	3 aB	1 ab	
Observed	..	535	: 196	: 215	: 46	(992 plants)
Expect	..	558	: 186	: 186	: 62	

Segregation is independent according to expectation.

II. A and C. A segregates 3 : 1, C 15 : 1. If independent segregation takes place, the expected ratio is—

		3 A	:	1 a	
		15 C	:	1 c	

		45 AC	15 aC	3 Ac	1 ac	
Observed	..	731	: 215	: 0	: 46	(992 plants)

The combination of "green apiculus" (*c*) with "coloured leaf-sheath, internode and stigma" (A) is not found. As in former cases of the sort, A is due to a single factor, C to a second factor interacting with the factor responsible for A in such a way that either or both produces colour. Thus

		12 A		4 a	
		AC : Ac		aC : ac	
		9 : 3		3 : 1	
		15 C		: 1 c	
or	..	12 AC :	3 aC :	0 Ac :	1 ac
Observed	..	731	: 215	: 0	: 46
Expect	..	744	: 186	: 0	: 62

III. B and C. B segregates 3 : 1, C 15 : 1, so this case is exactly comparable to II.

Ratio	..	12 BC :	3 bC :	0 Bc :	1 bc	
Observed	..	750	: 196	: 0	: 46	(992 plants)
Expect	..	744	: 186	: 0	: 62	

The combination of "coloured outer glumes" (B) with "colourless apiculus" (*c*) is not found.

6. Variety Bailabakri × Pookhi.

(A) The combination "leaf-sheath, internode, stigma" sticks together (24 exceptions out of 4,687 had green internodes) and gives 3 coloured : 1 colourless (total 7 families, 2·8 : 1).

(B) The "pulvinus and auricles" stick together, giving 9 coloured : 7 colourless (total 7 families, 1·2 : 1).

(C) Coloured outer and inner glumes give 3 coloured : 1 colourless (total 7 families, 3·1 : 1).

(D) Coloured apiculus gives 15 coloured : 1 colourless (total 7 families, 14·7 : 1).

I. A and B. A segregates 3 : 1, B 9 : 7. If independent segregation takes place, we expect—

	27 AB :	9 aB :	21 Ab :	7 ab	
Observed ..	2,607	: 0	: 878	: 1,202	(7 families of 4,687 plants)

The combination of "coloured pulvinus and auricles" (B) with "green leaf-sheath, internode, stigma" (*a*) is not found.

This case is comparable to previous ones. A is due to a single factor, B to a second additional factor interacting with the factor responsible for A in such a way that the presence of both is necessary for the production of colour. Thus we get—

$$\overbrace{\text{AB} : \text{Ab}}^{12\ \text{A}} : \overbrace{\text{aB} : \text{ab}}^{4\ \text{a}}$$

$$\underset{9\ \text{B}}{9} : \underbrace{3 : 3 : 1}_{7\ \text{b}}$$

or ...	9 AB :	3 Ab :	0 aB :	4 ab
Observed ..	2,607	: 878	: 0	: 1,202
Expect ..	2,636·43	: 878·81	: 0	: 1,171·75

II. A and C. A segregates 3 : 1, C 3 : 1.

Expected ratio	9 AC :	3 Ac :	3 aC :	1 ac	
Observed ..	2,666	: 819	: 905	: 297	(7 families of 4,687 plants)
Expect ..	2,636·37	: 878·79	: 878·79	: 292·93	

Segregation is independent and according to expectation.

III. A and D. A segregates 3 : 1, D 15 : 1, so expected ratio, if independent segregation takes place, is—

3 A : 1 a
15 D : 1 d

	45 AD :	15 aD :	3 Ad :	1 ad	
Observed ..	3,485	: 905	: 0	: 297	(7 families of 4,687 plants)

Here the combination of "green apiculus" (d) with " coloured leaf-sheath, internode, stigma " (A) is not found.

A is again due to a single factor, D to a second additional factor interacting with the factor for A, both or either producing colour. Thus

$$\begin{array}{c} \overbrace{AD \quad : \quad Ad}^{12\ A} \quad : \quad \overbrace{aD \quad : \quad ad}^{4\ a} \\ \underbrace{9 \quad : \quad 3 \quad : \quad 3}_{15\ D} \quad : \quad \underset{1\ d}{1} \end{array}$$

or ...	12 AD :	3 aD :	0 Ad :	1 ad	
Observed ...	3,485 :	905 :	0 :	297	(7 families of 4,687 plants)
Expect ..	3,515·16 :	878·79 :	0 :	292·93	

IV. B and C. B segregates 9 : 7, C 3 : 1. If independent segregation takes place, the expected ratio is—

	27 BC :	21 bC :	9 Bc :	7 bc	
Observed ..	1,992 :	1,579 :	615 :	501	(7 families of 4,687 plants)
Expect ...	1,977·33 :	1,537·92 :	659·1 :	512·64	

Here all expected combinations are found in expected ratios.

V. B and D. B segregates 9 : 7, D 15 : 1, so if independent segregation takes place, the expected ratio is—

	135 BD :	105 bD :	9 Bd :	7 bd	
Observed ..	2,607 :	1,783 :	0 :	297	(7 families of 4,687 plants)

The combination " coloured pulvinus and auricles " (B) with "green apiculus " (d) does not occur.

If B is due to two interacting factors, both necessary for the production of colour, and D due to the same two, but either alone capable of producing colour, we get the required result. Thus—

$$\begin{array}{c} \underset{9}{BD} \quad : \quad \overbrace{\underset{3}{Bd} \quad : \quad \underset{3}{bD} \quad : \quad \underset{1}{bd}}^{7b} \\ \text{(9 B)} \end{array}$$

$$\begin{array}{c} 9\ B \quad : \quad 7b \\ BD \quad : \quad \overbrace{Bd \quad : \quad bD \quad : \quad bd} \\ \underbrace{9 \quad : \quad 3 \quad : \quad 3}_{15\ D} \quad : \quad \underset{1\ d}{1} \end{array}$$

	9 BD :	6 bD :	0 Bd :	1 bd
Observed ..	2,607 :	1,783 :	0 :	297
Expect ..	2,636·37 :	1,757·58 :	0 :	292·93

VI. C and D. C gives 3 : 1, D 15 : 1, so expected ratio, if segregating independently, is—

	45 CD	: 15 cD	: 3 Cd	: 1 cd	
Observed ..	3,571	: 819	: 0	: 297	(7 families of 4,687 plants)

The combination of coloured glumes (C) with green apiculus (d) does not occur.

This is the same as previous cases, *viz.*, C due to a single factor, D to two factors, the factor responsible for C and an additional one, both or either capable of producing colour. Thus—

$$\overbrace{CD \quad : \quad Cd}^{12\ C} \quad : \quad \overbrace{cD \quad : \quad cd}^{4\ d}$$

$$\underbrace{9 \quad : \quad 3 \quad : \quad 3}_{15\ D} \quad : \quad \underset{1\ d}{1}$$

	12 CD :	3 cD :	0 Cd :	1 cd	
Observed	3,571	: 819	: 0	: 297	(7 families of 4,687 plants)
Expect ..	3,515·16	: 878·79	: 0	: 292·93	

7. Variety Agartollah × Variety C25.

(A) The combination "leaf-sheath, pulvinus, auricles, internode, outer glumes, inner glumes, apiculus" sticks together (1 exception was found in 4,669 plants examined, *viz.*, one plant with coloured apiculus and coloured glumes, but green leaf-sheath, internode, pulvinus and auricle), giving 9 coloured : 7 colourless (total 8 families, 1·3 : 1).

(B) The ligule gives 27 coloured : 37 colourless (total 8 families 1 : 1·3).

I. A and B. A segregates 9 : 7, B 27 : 37. If independent segregation takes place, the expected ratio is—

A 9 : 7 a
B 27 : 37 b

	243 AB :	189 aB :	333 Ab :	259 ab	
Observed ..	1,972	: 0	: 699	: 1,998	(4,669 plants, 7 families)

The combination of "green leaf-sheath, pulvinus, auricles, internode, outer glumes, apiculus" (a) with coloured ligule (B) does not occur.

Here A is due to two interacting factors, B to three, *viz.*, the two responsible for A together with an additional one, all three being necessary for the production of colour in B. Thus—

$$\begin{array}{l} \overbrace{ABC : ABc}^{36\ A\ :} : \overbrace{AbC : aBC : Abc : aBc : abC : ab}^{28\ a} \\ \underset{27\ B\ :}{27} : \underbrace{9 : 9 : 9 : 3 : 3 : 3 : 1}_{37\ b} \end{array}$$

or	..	27 AB	: 9 Ab	: 0 aB	: 28 ab
Observed	..	1,972	: 699	: 0	: 1,998 (4,669 plants, 7 families)
Expect	..	1,969·29	: 656·43	: 0	: 2,042·25

SUMMARY.

1. These colour characters which we have been discussing are sometimes simple, due to single factors or to several interacting factors. But frequently they are grouped into patterns or systems (*e.g.*, "leaf-sheath, apiculus, stigma"), which are inherited as a whole and segregate as if due to a single unit factor or to the same interacting factors. There is evidence, however, that the constituent parts of these patterns may be due to different factors, in which case they must be completely linked. The evidence consists, first, in the fact that rare instances are found where the patterns break down. Four such cases have been found: (1) In the cross Noachur × Pookhi, the pattern "coloured internode and stigma" was found to break down three times out of 1,199 plants examined, giving 3 types in F_2 with "coloured stigma and green internode". (2) In the same cross the pattern "coloured leaf-sheath and apiculus" broke down twice out of 1,199 plants, giving two types in F_2 with "coloured apiculus and green leaf-sheath." (3) In the cross Bailabakri × Pookhi, the pattern "coloured leaf-sheath, internode and stigma" broke down 24 times out of 4,687 plants examined, giving 24 plants with coloured leaf-sheath and stigma but green internode. (4) In the cross Agartollah × C25 the pattern "coloured leaf-sheath, pulvinus, auricles, internode, glumes, apiculus" broke down once out of 4,669 plants examined, *viz.*, one plant was found with colour in the glumes and apiculus, but with green leaf-sheath, internode, pulvinus and auricles.

These exceptional cases might be simply mistakes in observation, but all were very carefully examined and if colour was present, it must have been developed to so small a degree that it could not be observed by the most critical examination, whereas the type plants had the colour strongly developed. It is to be noted, moreover, that all are cases in which colour failed to develop in some part of the pattern, so they could not be due to accidental crossing, and moreover, the F_1 plants, though not bagged, were grown isolated in pots. Accidental mixture too is ruled out, as we have no such types. It would seem, therefore, that they are real breaks in the pattern systems, or, at any rate, extreme negative variations in the development of colour in the part concerned. If, however, they are breaks in the pattern systems and the patterns are due to one unit factor, it is difficult to understand by what mechanism these constituent parts of the pattern can break away, as they appear occasionally to do. Another case of a break in correlation is discussed below under grain colour, *viz.*, between red colour in the grain and colour in the ligule of the leaf. Similar cases of breaks in colour correlation have been described by Parnell[1] in rice ; and in other plants, notably by Emerson[2] in maize.

Again, it has been proved that in same varieties localizations such as leaf-sheath, apiculus and stigma stick together absolutely and belong to the same system, as in the crosses Pankhiraj × Pookhi and Matichak × Pookhi, where this pattern segregates 3 : 1 in F_2 (Nos. 1 and 2 discussed above) : but again in variety Noachur × Pookhi (No. 3 above) and others, the leaf-sheath and apiculus belong to a different system from the stigma, a system due to two interacting factors, segregating 15 : 1 ; whereas the stigma is united with the internode, and is due to a single factor and segregates 3 : 1.

2. These patterns or systems have been shown sometimes to segregate independently of other systems, giving all expected combinations in expected ratios in F_2, but frequently certain expected combinations are wanting, and the wanting combinations have been shown to be those which never occur in pure-line cultures. Examples of this are cases such as the cross Noachur × Pookhi.

In Noachur the system "leaf-sheath and apiculus" (A) segregates 15 : 1 ; the system "internode and stigma" (B) segregates 3 : 1.

On crossing with a colourless type (ab) you expect, if independent segregation is taking place,

$$\begin{array}{l}
15\ \mathrm{A} \ :\ 1\ \mathrm{a} \\
\ \ 3\ \mathrm{B} \ :\ 1\ \mathrm{b} \\
\hline
45\ \mathrm{AB} \ :\ 3\ \mathrm{aB} \ :\ 15\ \mathrm{Ab} \ :\ 1\ \mathrm{ab}
\end{array}$$

---

[1] Parnell, F. R., Ayyangar, G. N. R. and Ramiah, K. "The Inheritance of Characters in Rice, I." *Mem. Dept. Agri. India, Bot. Ser.*, Nov. 1917, vol. IX, no. 2.

[2] Emerson, R. A. "Genetic Correlation and Spurious Allelomorphism in Maize." *Twenty-fourth Ann. Rep., Agri. Exper. Station, Nebraska*, 1911, pp. 59—82.

Actually the combination of aB (green leaf-sheath and apiculus with coloured internode and stigma) is absent, and the ratio obtained is—

$$48\ \text{AB} \ :\ 0\ \text{aB} \ :\ 12\ \text{Ab} \ :\ 4\ \text{ab}$$

In such cases we must be dealing either with three factors, two of which are completely linked, or one factor is common to both systems, while a second additional factor, interacting with the common factor in such a way that the presence of either is sufficient for the production of colour, is responsible for the colour in the system "leaf-sheath and apiculus" (thus segregating 15 : 1). Thus—

$$\begin{array}{ccccccc} \multicolumn{5}{c}{15\ \text{A}} & & 1\ \text{a} \\ \multicolumn{5}{c}{\overbrace{\hphantom{\text{AB} : \text{aB} : \text{Ab}}}} & & \\ \text{AB} & : & \text{aB} & : & \text{Ab} & : & \text{ab} \\ 9 & : & 3 & : & 3 & : & 1 \\ \multicolumn{3}{c}{\underbrace{\hphantom{\text{AB} : \text{aB}}}} & & \multicolumn{3}{c}{\underbrace{\hphantom{\text{Ab} : \text{ab}}}} \\ \multicolumn{3}{c}{12\ \text{B}} & & \multicolumn{3}{c}{4\ \text{B}} \end{array}$$

or ... $12\ \text{AB} \ :\ 0\ \text{aB} \ :\ 3\ \text{Ab} \ :\ 1\ \text{ab}$

This type of segregation occurs very frequently.

Lastly, one instance has been found, *viz.*, in the cross Muramagar × Pookhi, in which the parental combinations (in this case coloured ligule and coloured outer and inner glumes ; colourless ligule and colourless glumes) occur more frequently than expectation if independent segregation is taking place, some of the ratios obtained indicating a coupling of the parental gametes in the neighbourhood of 7 : 1.

The final conclusions are—

1. These colour characters are frequently inherited in patterns of groups, due either to one and the same simple factor or to the same interacting factors ; or due to several factors linked together.

2. Considered in relation to other systems or patterns, independent segregation may take place, but frequently the groups are so inter-related that certain combinations, expected if independent segregation were taking place, are never found, and these combinations are those which are absent in pure-line cultures.

Grain colour.

The husked grain of rice is either some shade of red or white. A large number of crosses, both natural and artificial, have been examined with reference to grain colour and in all, with two exceptions, simple, independent 3 : 1 segregation has been found. As the inheritance of this character, with the exception of the cases referred to, presents no special interest, this account is confined to the exceptions.

1. The first of these was found in the cross Agartollah × C25 already described in connection with colour of the vegetative parts. In variety Agartollah, the grain is dark red with irregular black marks on the ventral edge giving the grain a slightly piebald appearance. On crossing with the colourless variety C25 (white grain), the F_1 is like the Agartollah grain but paler in colour, and in F_2 segregation is into 1 red piebald : 2 pale piebald : 1 white.

Actual figures obtained in three families examined for grain colour are given below :—

	Red piebald	Pale piebald	White
1 ..	141	329	149
2 ..	153	360	184
3 ..	177	342	177
TOTAL	471	1,031	510

It is, however, when we consider the relation of the grain colour to the colours in the vegetative parts, already described, that most interest attaches to this case.

We have already seen in variety Agartollah that the leaf-sheath, pulvinus and auricle, internode, outer glumes and apiculus form a pattern (A), due to 2 interacting factors and segregating 9 : 7 in F_2, while the ligule (B) is due to 3 factors and segregates 27 : 37, together giving, on crossing with the colourless (green) type Pookhi—

36 coloured leaf-sheaths, etc. (A) : 28 green leaf-sheaths (a)
ABC : ABc : AbC : aBC : abC : Abc : aBc : abc
27 : 9 : 9 : 9 : 3 : 3 : 3 : 1
27 coloured ligules (B) : 37 green ligules (b)
or .. 27 AB : 9 Ab : 0 aB : 28 ab

When we examine the distribution of the grain colour with reference to the above, we find, with a few exceptions, all class AB (coloured leaf-sheath, coloured ligule) have coloured grains ; all class Ab (coloured leaf-sheath, colourless ligules) have white grains : all class ab (both colourless) have coloured and white grains in a ratio of 3 : 1. All white grains therefore, with the few exceptions noted, are associated with colourless ligules, but not *vice versâ*.

The actual numbers observed in 4 families were as follows :—

	27 AB		:	9 Ab	:	28 ab	
Observed	1,226 ..		:	414	:	1,267 (4 families of 2,907 plants)	
	Coloured grain—white grain		:	White grains	:	Coloured grains—white grains	
	1,220	6		414		951	316
	27ABC			9ABc		9AbC, 9 aBC, 3 abC	3Abc, 3aBc, 1abc
Expect	1226·37			408·79		953·85	317·95

It thus appears that the factor responsible for colour in the grain is the third or C factor responsible for colour in the ligule. When C is present, the grain is coloured (with the six exceptions noted) ; when C is absent, the grain is white. Thus the colour in the grain must be due to this factor C, or to a factor completely linked with it. In this connection, the six exceptions with coloured ligules and white grains, are important, as furnishing further evidence in support of the latter view, for if one and the same factor is responsible for both ligule and grain, it is difficult to conceive by what mechanism these exceptions could come about. On the other hand, if two linked factors are responsible, then these exceptions are simply rare instances of breaks in the linkage, such as have already been noted above in the case of the colour patterns in the vegetative parts, in which some of the constituent parts have been seen occasionally to break away.

2. The second exceptional case has been found in the cross C9 × C25. Here the parent C9 had a dark red grain, C25 a white. On crossing, the F_1 was like the C9 grain but paler, and in F_2 segregated into four types of grain, dark red, pale red, pale amber and pure white. The figures obtained in 3 families examined are given in the table—

	Dark red	Pale red	Pale amber	White
1 ..	69	150	15	40
2 ..	48	119	34	25
3 ..	67	87	36	25
TOTAL	184	356	85	90
			177	
RATIO	1	2	1	

In this case the figures again approximate to a 1 : 2 : 1 ratio for red, pale red, and white, but the white class appears to be of two sorts, *viz.*, a pale amber class and a pure white.

SUMMARY.

Red colour in the grain ordinarily gives simple 3 : 1 segregation in F , and segregates independently of colour in the vegetative parts. Two cases, however, have been found in which segregation in F_2 is into 1 red : 2 pale red : 1 white, and in one of these, the white are of two sorts, in equal numbers. In the other, the colour in the grain has been proved to be due either to the same factor which is responsible for colour in the ligule, or to a factor completely linked with this factor. The fact that there are found a few cases of plants with coloured ligules and white grains, is evidence in favour of the latter view.

Colour of ripe glumes.

The colour of the ripe glumes of rice, *i.e.*, the husk, is generally some shade of yellow, red or black, or a mixture of these. The colour is often uniform, but piebald grains are frequent.

These ripe glume colours have been studied in all the seven varieties discussed above with reference to colour in the vegetative parts, and those in which definite results have been obtained are described below, together with a few others.

1. Variety Pankhiraj × Pookhi. Variety Pankhiraj ripens brownish-black (Fig. 1) ; variety Pookhi ripens yellow-brown. On crossing, the ripe F_1 glume is like Pankhiraj, brown-black, and in F_2 segregation is complete into 3 Pankhiraj glumes : 1 Pookhi glume. Actual figures obtained are given in the table.

Parents	F_2			Ratio
	Brown-black	:	Yellow-brown	
Pankhiraj × Pookhi	69	:	26	
	157	:	52	
	206	:	57	
	93	:	23	
TOTAL	525	:	158	3·3 : 1

We have seen above that the colour in the vegetative parts of Pankhiraj forms a pattern, *viz.* "coloured leaf-sheath, apiculus, stigma," segregating 3 coloured : 1 green in F_2. Considered in relation to this colour in the vegetative parts, we find the colour of the ripe glumes segregates independently, giving 9 coloured, black : 3 coloured, yellow-brown : 3 green, black : 1 green, yellow-brown. Actual numbers observed were 401 coloured black : 114 green, black : 113 coloured, yellow-brown : 44 green, yellow-brown.

2. Variety Matichak × Pookhi. The ripe glume of Matichak (Fig. 2) is almost indistinguishable from that of Pankhiraj, and segregation is in the same simple 3 : 1 ratio of black : yellow-brown, and independent of colour in the vegetative parts, as in No. 1.

Actual figures obtained in three families examined were—

	Coloured plants Black glumes	Coloured plants Yellow glumes	Green plants Black glumes	Green plants Yellow glumes
	225	59	64	30
	279	72	127	27
	202	47	48	16
TOTAL	706	178	239	73

3. Variety Noachur × Pookhi. Here the glume colour of both parents is almost indistinguishable and incapable of analysis in F_2.

4. Variety Muramagar × Pookhi. The glume colour of both parents is almost indistinguishable and incapable of analysis.

5. Variety Surjamukhi × Pookhi. The ripe glume of Surjamukhi is a brick-red colour (Fig. 5). In the F_1 of this cross, the Pookhi glume (yellow-brown) is dominant, and in F_2 segregation is into 3 Pookhi glumes : 1 Surjamukhi.

Actually observed 742 : 250.

Here again the ripe glume colour segregates independently of the colour in the vegetative parts, which have already been described. At flowering time, the glumes which ripen yellow-brown are pure green in colour, those which ripen red are a golden green.

6. Variety Bailabakri × Pookhi. The glume colours of both parents are almost indistinguishable, and analysis is not possible in F_2.

7. Variety Agartollah × Pookhi. The glume colours of both parents are almost indistinguishable and analysis is not possible.

In addition to the above, two other crosses have been examined with reference to ripe glume colour, and have given definite results. These are described below.

1. Rajshahi 22 × Bogra 17. Rajshahi 22 has glumes ripening brick-red like Surjamukhi, Bogra ripens yellow. Both varieties are colourless (green) as regards the growing vegetative parts. In F_1, yellow ripe glumes are dominant, and in F_2 segregation is as shown below.

Rajshahi 22 × Bogra 17

Yellow	Intermediate (yellow & red)	Red
58	52	7
96	58	9

An exactly similar result was obtained on crossing the same Rajshahi 22 with another variety with similar yellow-coloured glumes.

Rajshahi 22 × Chittagong 22

	Yellow	Intermediate (yellow & red)	Uniform Red
	88	61	9
	82	58	14
	47	26	8
Total of both	371	255	47

On examination it is seen that the figures closely approximate to a ratio of 9 yellow : 6 intermediate : 1 red, the expectation on this basis being 378·5 : 255·44 : 42·06.

On the above basis, the following results should obtain in F_3. The yellow will be of three constitutions (1) pure yellow AB, (2) yellow impure for one factor, AaBB or AABb, (3) yellow impure for both, as in F_1. These types will give (1) pure yellow, (2) 3 yellow : 1 intermediate, (3) 9 yellow : 6 intermediate : 1 red. Reds being recessive will give reds only.

The following actual results were obtained from F_2 yellow and red-glumed plants.

F_2 1917	Yellow	Intermediate	Red	Ratio
YELLOW—				
2 families ..	182	—	—	Pure yellow
	94	—	—	
8 families ..	215	67	—	
	208	59	—	
	90	30	—	Yellow : Intermediate
	114	43	—	1,222 : 318
	81	26	—	expected
	140	41	—	1201·5 . 401·5
	134	43	—	3 : 1
	240	71	—	
5 families ..	105	60	8	Yellow : Intermediate : Red
	94	70	6	638 : 373 : 51
	61	46	4	expected
	239	129	20	597·5 398·2 : 66·3
	139	68	13	9 : 6 1
RED—				
8 families ..	..	..	91	
	..	..	193	
	..	..	144	Yellow : Intermediate : Red
	..	..	296	8 : 7 : 1,544
	3	1	205	expected
	2	2	251	pure red
	2	4	268	
	1	..	96	

The excess of yellows in the families from yellow parents and the small numbers of yellow and intermediate in the families from red parents can easily be explained by natural crossing, as the F_2 plants were not protected.

2. Variety Kataktara × Charnak. Variety Kataktara has again a brick-red husk, Charnak a pale-yellow husk. The Charnak husk is dominant, and in F_2 segregation is into 3 yellow : 1 red.

At flowering time the glumes which ripen yellow are pale green, those which ripen red are golden-green in colour. There is no connection otherwise between the ripe glume colours and the colours in the vegetative parts.

SUMMARY.

In the results discussed above, definite ratios have been obtained in five cases. In two of these, Pookhi was crossed with varieties having glumes ripening black. In both, the Pookhi husk (yellow-brown) was recessive, and segregation was into 3 black : 1 yellow-brown.

In another, Pookhi was crossed with a variety with glumes ripening red. Here Pookhi was dominant, and segregation into 3 yellow-brown : 1 red.

A similar result was obtained in the cross Charnak × Kataktara. The yellow glume of Charnak was dominant over the red of Kataktara, and segregation was into 3 yellow : 1 red.

In still another cross between yellow and red, yellow was again dominant, but segregation was into 9 yellow : 6 yellow and red : 1 pure red.

In no case has any connection been proved between the ripe glume colours and the colours in the vegetative parts previously discussed.

APPENDIX I.

COLOUR COMBINATIONS OF 211 COLOURED VARIETIES OF RICE.

I. Leaf-sheath coloured, apiculus coloured, stigma coloured.

Class No.	Pulvinus	Auricle	Ligule	Node	Internode	Outer glumes	Inner glumes	Awns	No. of types
1	—	—	×	—	—	—	—	—	1
2	—	—	—	—	×	—	—	—	2
3	×	×	—	—	—	—	—	—	1
4	×	—	—	—	×	—	—	—	1
5	—	—	—	×	×	—	—	—	1
6	—	—	×	—	—	—	—	×	1
7	×	×	—	—	×	—	—	—	1
8	×	×	—	×	—	—	—	—	1
9	×	—	—	×	×	—	—	—	2
10	—	—	×	×	×	—	—	—	1
11	—	—	—	×	×	—	—	×	5
12	—	—	×	×	×	—	×	—	1
13	×	×	×	—	—	—	—	×	1
14	×	×	—	×	×	—	—	—	30
15	×	—	×	×	×	—	—	—	1
16	×	×	—	—	×	—	—	×	1
17	×	—	—	×	×	—	—	×	2
18	—	—	×	×	×	—	—	×	1
19	×	×	×	×	×	—	—	—	7
20	×	×	—	×	×	—	—	×	24
21	×	—	×	×	×	—	—	×	1
22	—	×	×	—	×	×	—	×	1
23	×	×	—	×	×	—	×	—	1
24	—	—	×	×	×	×	×	×	1
25	×	×	×	×	×	—	—	×	6
26	×	×	—	×	×	×	—	×	1
27	×	×	—	×	×	×	×	×	1
28	×	×	×	×	×	×	—	×	1

× = coloured.
— = green (colourless).

APPENDIX I—*concld.*

II. Leaf-sheath coloured, apiculus coloured, stigma white.

Class No.	Pulvinus	Auricle	Ligule	Node	Internode	Outer glumes	Inner glumes	Awns	No. of types
1	—	—	—	—	×	—	—	—	1
2	—	—	—	—	×	—	×	—	2
3	—	—	—	—	—	×	×	—	1
4	—	—	—	—	×	×	×	—	20
5	×	×	—	—	×	—	×	—	1
6	—	—	—	×	×	×	×	—	1
7	—	—	—	—	×	×	×	×	13
8	×	×	—	—	×	×	×	—	4
9	×	×	—	×	×	—	×	—	2
10	×	—	—	—	×	×	×	×	3
11	×	×	—	—	—	×	×	×	1
12	×	—	—	×	×	×	×	—	1
13	×	×	×	—	×	×	×	—	4
14	×	×	—	×	×	×	×	—	5
15	×	×	×	—	—	×	×	×	1
16	×	×	—	—	×	×	×	×	1
17	×	×	×	×	×	×	×	—	3

III Leaf-sheath green, apiculus coloured, stigma white.

Class No.	Pulvinus	Auricle	Ligule	Node	Internode	Outer glumes	Inner glumes	Awns	No. of types
1	—	—	—	—	—	—	—	×	2
2	—	—	—	—	—	×	×	—	28
3	—	—	—	—	—	×	—	×	3
4	—	—	—	—	—	×	×	×	13
5	×	—	—	—	—	×	×	×	2
6	×	×	—	—	—	×	×	—	1

× = coloured.
— = green (colourless).

APPENDIX II.

Colour combinations in seven pure-line types of rice and in F_2 of crosses between them and green varieties.

Varieties.		Leaf-sheaths	Pulvinus	Auricle	Ligule	Internode	Outer glumes	Inner glumes	Apiculus	Stigma	No. of families examined	Total No. observed	
Pookhi		—	—	—	—	—	—	—	—	—			
C 25		—	—	—	—	—	—	—	—	—			
Pankhiraj		×	—	—	—	—	—	—	×	×			
Matichak		×	—	—	—	—	—	—					
Noachur		×	—	—	—	×	×	×	×	×			
Muramagar		×	—	—	×	×	×	×	×	×			
Surjamukhi		×	—	—	—								
Bailabakri		×	×	×	—	×	×	×	×				
Agartollah		×	×	×	×	×	×	×	×	—			
Pankhiraj × Pookhi, F_2													
Class	I	×	—	—	—	—	—	—	×	×	5	1,015	1,332
,,	II	—	—	—	—	—	—	—	—	—		317	
Matichak × Pookhi, F_2													
Class	I	×	—	—	—	—	—	—	×	×	9	2,703	3,532
,,	II	—	—	—	—	—	—	—	—	—		829	

× = coloured.

— = green (colourless).

APPENDIX II—*contd.*

Varieties		Leaf-sheaths	Pulvinus	Auricle	Ligule	Internode	Outer glumes	Inner glumes	Apiculus	Stigma	No. of families examined	Total No. observed	
Noachur × Pookhi, F_2													
Class	I	×	—	—	—	×	×	×	×	×	3	648	1,199
,,	II	×	—	—	—	×	—	—	×	×		219	
,,	III	×	—	—	—	—	—	—	×	×		3*	
,,	IV	×	—	—	—	—	×	×	×	—		259	
,,	V	—	—	—	—	—	—	—	×	—		2*	
,,	VI	—	—	—	—	—	—	—	—	—		68	
Muramagar × Pookhi, F_2													
Class	I	×	—	—	×	×	×	×	×	×	4	1,253	3,016
,,	II	×	—	—	—	×	×	×	×	×		394	
,,	III	×	—	—	×	×	—	—	×	×		393	
,,	IV	×	—	—	—	×	—	—	×	×		158	
,,	V	—	—	—	—	—	—	—	—	—		818	
Surjamukhi × Pookhi, F_2													
Class	I	×	—	—	—	×	×	×	×	×	1	535	992
,,	II	×	—	—	—	×	—	—	×	×		196	
,,	III	—	—	—	—	—	×	×	×	—		215	
,,	IV	—	—	—	—	—	—	—	—	—		46	

× = coloured.
— = green (colourless).
* Breaks in the pattern systems.

APPENDIX II—*concld.*

Varieties	Leaf-sheaths	Pulvinus	Auricle	Ligule	Internode	Outer glumes	Inner glumes	Apiculus	Stigma	No. of families examined	Total No. observed	
Bailabakri × Pookhi, F_2												
Class I	×	×	×	—	×	×	×	×	×	7	1,992	4,687
„ II	×	—	—	—	×	×	×	×	×		674	
„ III	×	×	×	—	×	—	—	×	×		507	
„ IV	×	×	×	—	×	—	—	×	×		108	
„ V	×	—	—	—	×	—	—	×	×		180	
„ VI	×	—	—	—	—	—	—	×	×		24*	
„ VII	—	—	—	—	—	×	×	×	—		905	
„ VIII	—	—	—	—	—	—	—	—	—		297	
Agartollah × C 25, F_2												
Class I	×	×	×	×	×	×	×	×	—	8	1,972	4,669
„ II	×	×	×	—	×	×	×	×	—		698	
„ III	—	—	—	—	—	—	—	—	—		1,998	
„ IV	—	—	—	—	—	×	×	×	—		1*	

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and subsidiary to, the breeding of improved strains. It is frequently impossible, therefore, immediately to follow up and finish off points of interest as they arise; moreover it is often uncertain as to when they will be taken up again. In the circumstances it has been decided to publish any definite results as they become available without waiting for a degree of completion that may never be possible.

Characters investigated.

1. Golden colouring of inner glumes with modifying factors.

Some earlier results in connexion with these characters were given in Part I, pp. 80–86. The factors concerned have now been worked out in greater detail, though there are still certain points on which evidence is wanting.

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[1] Parnell, F. R., and others. *Mem. Dept. Agri. India, Bot. Series,* IX, no. 2, Nov. 1917.

Four factors have been identified with certainty and one more, *E*, is put down provisionally. Adopting the ‘presence and absence’ notation, their description is as follows :—

G produces *dark gold.*

I modifies all golden colouring to a corresponding degree of *dark furrows* and inhibits golden colouring of the internode.

P produces a *piebald* pattern on dark gold or dark furrows.

T gives *tipped gold* from dark gold, *ripening straw* from ripening gold and *granular dark furrows* of degrees.

E regarded, provisionally, as giving *even-colouring* by prevention of *mottling.*

In the absence of *G*, and apart from other complications, the inner glumes are *ripening gold*. This colouration is quite distinctive, the glumes being almost green at flowering and passing through lemon yellow to a dull light gold at maturity (Plates I and II, fig. 1), unset grains remaining green. No case of the absence of this colouring, other than through inhibition, has been recorded, hence its production is not assigned to any factor in the notation employed.

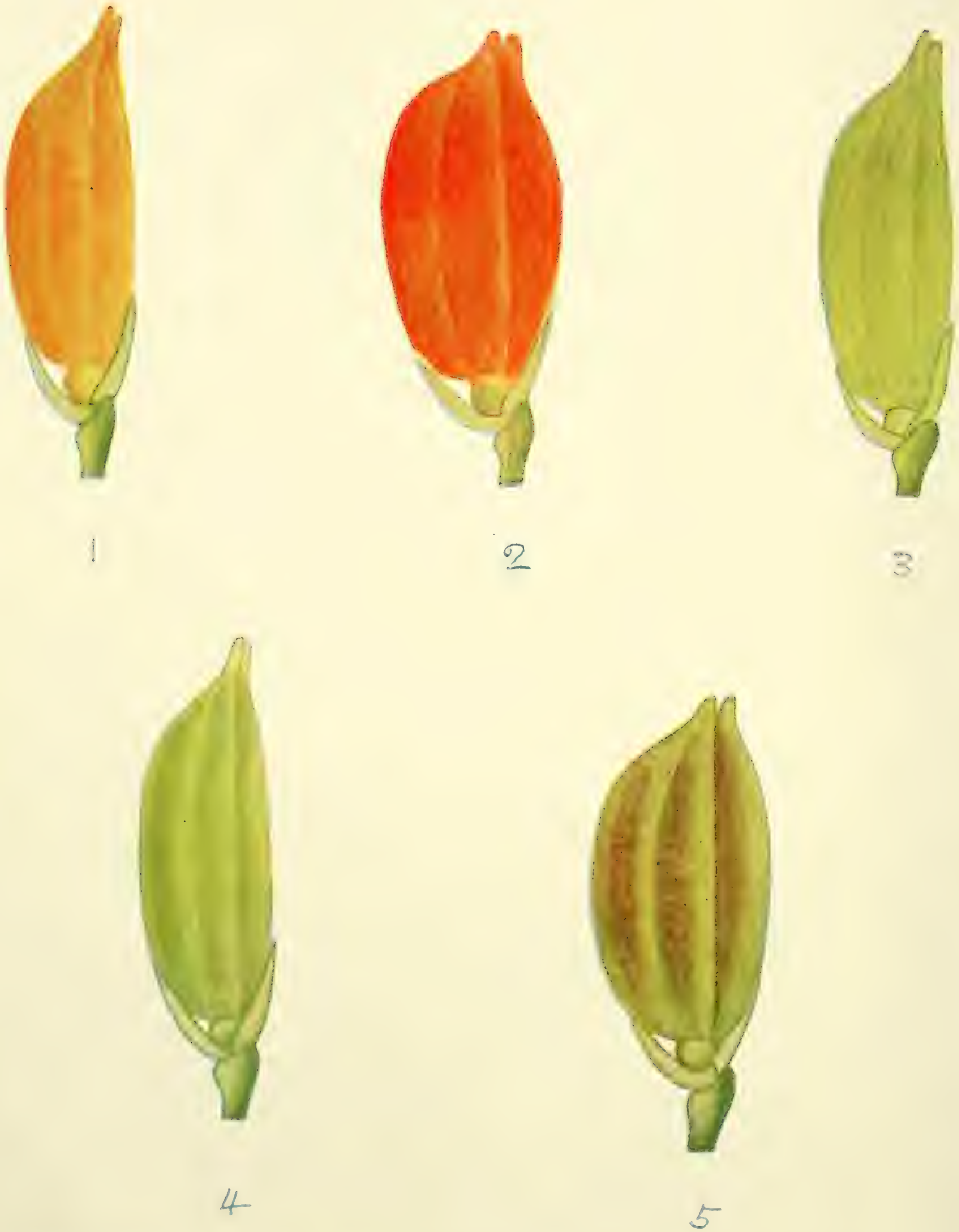
A *golden yellow internode* is present in all plants with golden glumes, as also in the ripening straw type where ripening gold is inhibited by *T*. In other words, it occurs in all plants in the absence of *I*.

The factor G.

In the absence of *I* this factor produces a *dark gold* colouring of the inner glumes. The latter are definitely gold at flowering and darken as the grain develops to a reddish brown at maturity (Plate I, fig. 2, and Plate II, fig. 4). In unset grains the glumes do not darken appreciably with age.

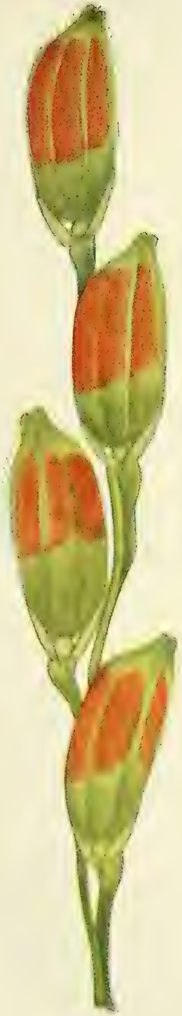
In the presence of *I* all trace of gold disappears and it is replaced by a blackish brown pigment, showing mainly in the furrows of the glumes, giving the type described as *dark furrows* (Plates I and II, fig. 5). From the results of a large number of crosses it appears that *dark furrows* and *dark gold* are produced by the same factor, *G*, and that the presence or absence of *I* determines which colour shall develop.

A similar modification takes place in the case of *ripening gold* which, in the presence of *I*, is replaced by a very dilute form of dark furrows described as *ripening furrows* (Plate I, fig. 4, and Plate II, fig. 2). Thus *G* may be simply an intensifying factor which darkens the *ripening* gold and furrows types.

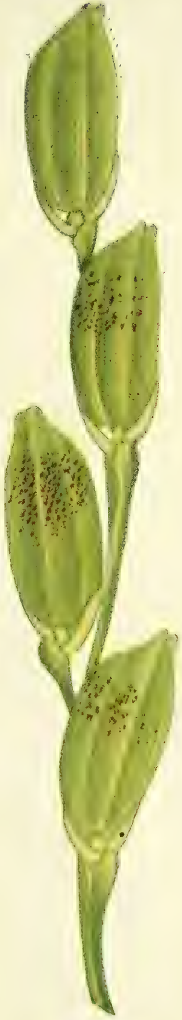


1. Ripening gold: 2. Dark gold: 3. Ripening straw: 4. Ripening furrows: 5. Dark furrows

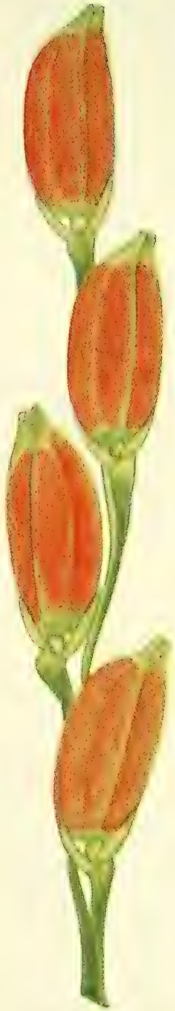
PLATE I.



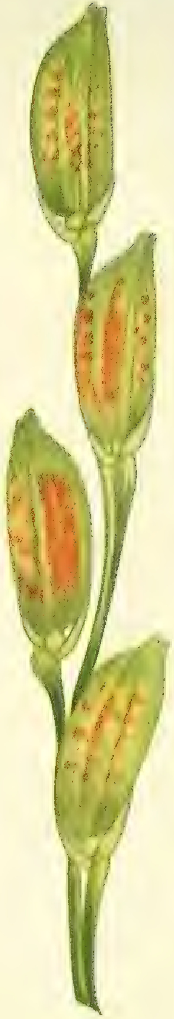
6.
Piebald gold.



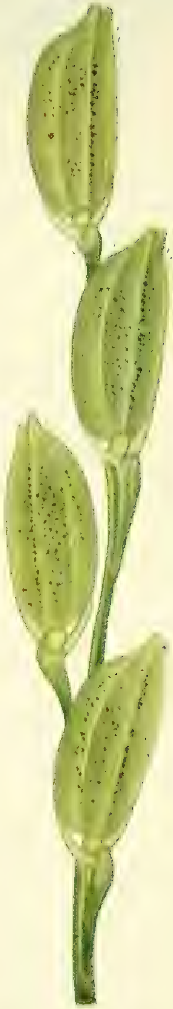
7.
Piebald dark furrows.



8.
Tipped gold.



9.
Patchy gold.



10.
Granular furrows.

Dark gold, *G G i i*, × *ripening gold*, *g g i i*, gives an F_1 rather lighter than the dark gold parent. In F_2 an ordinary *3 : 1* ratio of *dark gold : ripening gold* is obtained, as shown by the figures given below. The ripening golds are easily separable with absolute certainty. In the dark golds two groups can be distinguished since the heterozygotes are rather lighter in colour than the pure dark golds. A strictly accurate separation is not possible, however, as shown by the fact that of 112 plants described as dark 13 proved heterozygous, and of 117 medium 2 bred true.

Table I gives figures for a number of families in which this separation was made and shows a near approximation to the expected *1 : 2 : 1* ratio.

TABLE I.

Segregation of G g i i .

Origin of parent	Ref. No.	Dark gold G G i i	Medium gold G g i i	Ripening gold g g i i
Medium golds from No. 1247 N ..	1793 N	231	440	206
	1797 N	176	409	195
	1798 N	181	411	176
	1799 N	180	407	198
	1800 N	218	463	232
Miscellaneous ..	8 lots	1,658	3,372	1,674
TOTAL ..		2,644	5,502	2,681
* *Calculated 1 : 2 : 1* ..		*2,707* :	*5,413* :	*2,707*

* N.B. *All calculated ratios are given to the nearest whole number to avoid fractions.*

The following total figures were obtained by combining the families of Table I with others in which only the two main groups were separated :—

	Dark gold G i	Ripening gold g i
29 families	16,104	5,483
Calculated 3 : 1 ..	*16,190* :	*5,397*

Entirely similar results are given in the segregation of the type *G g II* where dark furrows replace gold. Here again three types can be distinguished in F_2, though in this case there is some uncertainty in separating the recessive group of ripening furrows from the medium furrows. Thus of 21 plants assigned to the former group 1 proved heterozygous, whereas of 26 noted as medium 2 bred true to ripening furrows.

The results of a number of families in which three groups were separated are given in Table II, which shows a *1 : 2 : 1* ratio.

TABLE II.

Segregation of G g I I.

Origin of parent	Ref. No.	Dark furrows G G I I	Medium furrows G g I I	Ripening furrows g g I I
Cross No. 1236 N ..	1760 N	288	568	254
Medium furrows from No. 1760 N ..	2221 N	91	180	105
	2222 N	72	175	67
	2223 N	67	117	64
	2225 N	99	219	129
	2226 N	144	310	151
	2229 N	79	148	81
	2230 N	67	148	72
Miscellaneous ..	4 lots	409	839	428
TOTAL ..		1,316	2,704	1,351
Calculated 1 : 2 : 1 ..		*1,343* :	*2,685* :	*1,343*

The total figures for all families showing this segregation, two groups only being separated, are as follows :—

		Dark furrows G I		Ripening furrows g I
23 families ...	...	9,538		3,243
Calculated 3 : 1	..	*9,586*	:	*3,195*

The factor I.

As already noted the presence of *I* changes any form of golden colouring of the inner glumes to a corresponding degree of dark furrows. This factor was described in Part I, p. 82, as an inhibitory factor for gold, and figures were given in Table III, p. 81, showing a *3 : 1* ratio of *green : gold* due to this segregation. The so-called green types, in reality various forms of dark furrows, were described as green merely to indicate the absence of gold. The same *3 : 1* ratio for the presence and absence of *I* has been repeated in a very large number of later families, the two groups appearing, in all cases, being corresponding types of dark furrows and gold respectively.

Where the golds are splitting into different groups, due to the segregation of *G* or one of the modifying factors, the dark furrows show the same groups. An example of this is given in Table III, showing the segregation occurring in the *G g I i* type, where the usual three groups appear in both golds and furrows.

The first two families are F_2's of a cross between dark furrows, *G G I I*, and *ripening gold*, *g g i i*; the others are from plants of *G g I i* constitution extracted from a more complicated cross.

TABLE III.

Segregation of G g I i .

Origin of parent	Ref. No.	FURROWS			GOLD		
		Dark G G I	Medium G g I	Ripening g g I	Dark G G i	Medium G g i	Ripening g g i
F_1, G G I I × g g i i ..	2569 2573	143 237	325 482	151 267	54 81	110 170	58 74
Cross No. 1236 N ..	1763 N	188	385	193	80	126	75
Medium furrows from No. 1763 N ..	2237 N 2240 N 2244 N	126 80 75	230 165 168	126 78 86	43 24 27	86 49 59	50 26 30
Miscellaneous ..	3 lots	215	412	237	63	166	67
TOTAL ..		1,064	2,167	1,138	372	766	380
3 : 6 : 3 : 1 : 2 : 1 ..		*1,104* :	*2,207* :	*1,104* :	*368* :	*736* :	*368*
			4,369			1,518	
3 : 1			*4,415*	:		*1,472*	

Counts have been made in a very large number of families showing segregation of *I* and the total figures are as follows :—

		Dark furrows (various)		Gold (various)
120 families	..	98,541		32,126
Calculated 3 : 1	..	*98,000*	:	*32,667*

Piebald factor P

The action of this factor has been described in Part I, pp. 85 and 86, where figures are given, Table VII, showing a simple *3 : 1* ratio of *piebald : self-colour* in both gold and dark furrows. Only one further family giving this type of segregation has been examined; this was the F_2 of a cross between *dark gold*, *G G i i pp*, and *piebald dark furrows*, *G G I I P P*.

The following figures, showing approximately the *9 : 3 : 3 : 1* ratio expected, were obtained :—

	Dark furrows		Gold	
	Piebald G I P	Self-colour G I p	Piebald G i P	Self-colour G i p
No. 1285 N ..	969	278	283	97
9 : 3 : 3 : 1 ..	*915* :	*305* :	*305* :	*102*

The piebald types are shown in Plate I, figs. 6 and 7.

The effect of the piebald factor on the ripening gold type has not yet been noted.

The factor T.

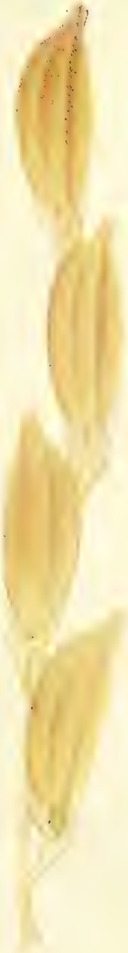
The action of this factor is very similar to that of *P*, since it limits the colouring due to *G*, though to a smaller extent. In homozygous dark golds it produces *tipped gold*, a type in which small green areas appear at the apex and base of the glumes (Plate I, fig. 8). The green areas vary somewhat in size and occasionally the lower one is absent, the base of the grain being entirely gold. In heterozygous golds, where the colour is lighter, the restriction of the gold colour is greater and much less regular, giving a very variable type, *patchy gold* (Plate I, fig. 9).

The restriction of dark furrows is very irregular, the result being a considerable reduction of the pigment, which assumes a granular appearance, and its restriction roughly to the middle part of the grain. The type produced, *granular dark furrows* (Plate I, fig. 10), shows very considerable variation. The reduction of pigment is much greater in the *Gg* type, as with the golds, but it is not possible actually to separate two types corresponding to tipped and patchy golds.

The factor *T* inhibits ripening gold almost entirely, giving *ripening straw* in which the glumes are slightly yellowish in early stages (Plate I, fig. 3), but ripen to ordinary straw-colour (Plate II, fig. 3). Occasionally a few grains show traces of gold in very small patches and there is some indication that this is more common in heterozygotes of the *Tt* type. The golden internode is not affected but persists in the ripening straw type as one of its distinctive features.

The results given in Part I, pp. 82-84 and Tables IV–VI, are now easily explained. The original cross that gave the families of Table IV

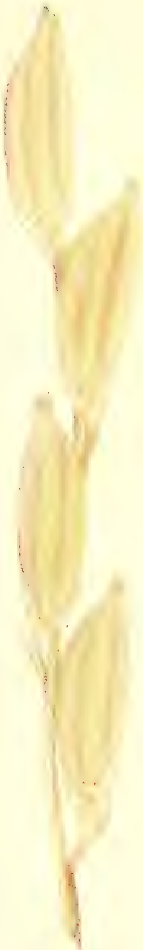
PLATE II.


1

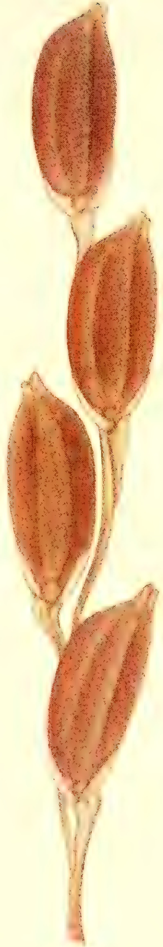
1. Ripening gold.

2

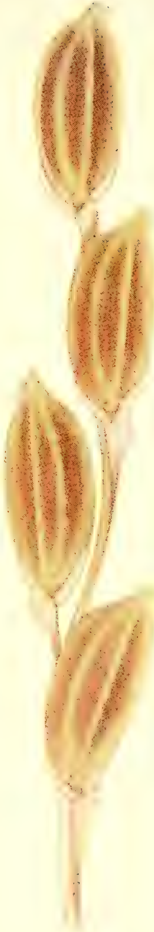
2, Ripening furrows.


3

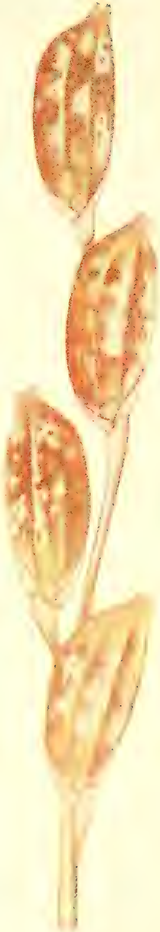
3. Ripening straw.


4

4. Dark gold.


5

5. Dark furrows.


6

6. Mottled dark gold.

was obviously of the constitution *G g T t,* and the two families followed up were—

No. 431 *g g T t* giving a simple *3 : 1* ratio of *ripening straw : ripening gold,* Table V.

No. 432 *G g T T* giving a *1 : 2 : 1* ratio of *tipped gold : patchy gold : ripening straw,* Table VI.

In both cases further generations confirmed these results.

A large amount of material arising from various crosses has now been examined and in all cases the above explanation of the behaviour of *T* is in strict accordance with the results. It appears, however, that there may be some other factor producing slight modifications. Thus in some groups the tipped golds are quite distinct, whereas in others they are not easily separable from some of the patchy golds. Similarly in some groups the ripening straws constantly show specks of gold, whereas in others this is very rare.

Below are given the results from two crosses between pure types, and also the summarized results of several generations from certain natural crosses in which the same factors are concerned.

Tipped gold, G G T T, × *dark gold, G G t t,* gave *tipped gold* in F_1. A simple *3 : 1* ratio of *tipped gold : dark gold* resulted in F_2 as follows :—

	Tipped gold G T	Dark gold G t
No. 2596 ..	599	184
Calculated 3 : 1 ..	*587*	*196*

Dark gold, G G t t × *ripening straw, g g T T,* gave *patchy gold* in F_1. Six groups appeared in F_2 but patchy and tipped golds were counted together, as also dark and medium golds. The figures for the four main groups separated were as follows :—

	GOLD		RIPENING	
	Tipped & patchy G T	Dark & medium G t	Straw g T	Gold g t
No. 2581	1,335	455	443	170
Calculated 9 : 3 : 3 : 1	*1,351*	*451*	*451*	*150*

Similar results were given by a natural cross of which the progeny have been followed up in some detail. The F_1 appeared as a *patchy gold* plant in a family giving a simple *3 : 1* ratio of ripening straws to ripening golds. This cross, No. 748 N, was obviously of the constitution *G g T t,* as No. 2581 above, since it gave the same groups in F .

At that time, however, the behaviour was not understood and the groups were not properly separated; thus no numbers can be given for F_2. The results given by plants carried forward in F_3 and F_4 are summarized in Table IV where it will be seen that the various types are behaving according to expectation.

TABLE IV.

F_3 and F_4 of No. 748 N.

Parent characters	No. of lots	Tipped gold G G T	Patchy gold G g T	Gold G t	Ripening straw g T	Ripening gold g t
Dark gold ..	9	..	..	pure	..	..
Medium gold ..	14 *(3 : 1)*	.. ..	.. ..	9,511 *9,542*	.. ..	3,212 *3,181*
Ripening gold ..	21	..	..	..	..	pure
Ripening straw (all slight gold patches)	5 *(3 : 1)*	.. ..	.. ..	.. ..	5,017 *4,970*	1,610 *1,657*
Patchy gold ..	13 *(9 :3 :3:1)*	6,491 *6,397*		2,016 *2,132*	2,183 *2,132*	682 *711*
Ditto ..	4 *(1:2:1)*	650 *666*	1,323 *1,331*	..	690 *666*	..
Tipped gold ..	1	pure	..	..	..	..
Ditto ..	5 *(3 : 1)*	2,768 *2,679*	.. ..	804 *893*	.. ..	.. ..

Two crosses, appearing as *granular dark furrows* in a pure ripening gold lot, gave similar results to the above with the added complication of segregation for the factor *I*. The F_2's were not properly separated into groups for counting but the same groups appeared as in Nos. 2581 and 748 N above, together with the corresponding dark furrows types, *viz.*. *granular dark furrows, dark furrows, granular ripening furrows* and *ripening furrows*.

One family only, No. 1236 N. was followed up. The gold types, where *I* was absent, gave results similar to those of Table IV. The lots showing segregation for *T* are summarized in Table V. There was some difficulty in separating tipped and patchy golds in some of these lots, also in separating the lowest grades of patchy gold from some of the ripening straws showing the maximum amount of gold in slight patches.

TABLE V.

F_3 *and* F_4 *of No.* 1236 *N, gold lots.*

Parent characters	No. of lots	Tipped gold G G T	Patchy gold G g T	Gold G t	Ripening straw g T	Ripening gold g t
Tipped gold ..	3 *(3 : 1)*	2,091 *2,074*	.. ..	675 *691*	.. ..	.. ..
Patchy gold ..	24 *(1 : 2 : 1)*	3,123 *3,048*	6,018 *6,095*	.. ..	3,050 *3,048*	.. ..
Ditto ..	13 *(9 : 3 : 3 :1)*	4,625 *4,621*		1,389 *1,540*	1,680 *1,540*	522 *513*

Of dark furrows types the majority that were carried on were of the medium dark furrows type and some of their results have already been given in Tables II and III.

Only eight granular furrows plants were carried on and these gave five types of segregation in F_3, as shown by Table VI.

TABLE VI.

F_3 *of No.* 1236 *N, dark furrows lots.*

Parents	No. of lots	Granular dark furrows GTI	Dark furrows GtI	Granular ripening furrows gTI	Ripening furrows gtI	Tipped gold GGTi	Gold Gti	Ripening straw gTi	Ripening gold gti
Granular ripening furrows ..	1 *(9 : 3 : 3: 1)*	.. ..	.. ..	629 *607*	195 *202*	.. ..	.. ..	188 *202*	68 *67*
Granular dark furrows ..	1 *(9:3:3:1)*	632 *621*	217 *207*	178 *207*	78 *69*	.. ..	.. ..	.. ..	.. ..
Ditto ..	1 *(3 : 1)*	483 *489*	169 *163*	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
Ditto ..	4 *(3 : 1)*	3,803 *3,837*	.. ..	.. ..	.. ..	1,313 *1,279*	.. ..	.. ..	.. ..
Ditto ..	1 *(9:3:3:1)*	505 *517*	156 *172*	.. ..	.. ..	176 *172*	82 *57*	.. ..	.. ..

Several other natural crosses have been found in which the factors *T* and *I* were concerned. Some of these, *granular dark furrows* appearing in a pure tipped gold type, were carried on and gave the results shown in Table VII. Some of the figures are not as near as could be desired to expectation but there is no doubt that they represent the ratios noted.

TABLE VII.

Segregation of G G T t I i.

Origin of parent	Ref. No.	Granular dark furrows	Dark furrows	Tipped gold	Dark gold
		G G T I	G G t I	G G T i	G G t i
Natural crosses	1272	846	305	281	103
	1275 N	2,945	775	838	264
	2 lots	3,393	1,022	957	360
No. 1272 F_2	4 lots	2,660	898	824	270
No. 1275 N F_2	4 lots	2,570	793	874	234
	Total	12,414	3,793	3,774	1,231
	(9:3:3:1)	*11,932*	*3,977*	*3,977*	*1,325*
No. 1272 F_2	3 lots	2,466	..	889	..
No. 1275 N F_2	1 lot	1,003	..	322	..
	Total	3,469	..	1,211	..
	(3 : 1)	*3,510*	..	*1,170*	..
No. 1272 F_2	2 lots	1,599	592	..	..
No. 1275 N F_2	3 lots	2,951	733	..	..
	Total	4,550	1,325	..	..
	(3 : 1)	*4,406*	*1,469*	..	..

Mottling.

On several occasions it was noted that certain families derived from natural crosses, splitting for some type of gold or dark furrows colouring, showed a number of plants with *mottled* grain. At first this was put down to some extraneous cause such as damage by insects or discolouration due to the grain coming in contact with water. It was found, however, that when such plants were carried forward they bred true to this character. The mottling is not seen till the grain is practically ripe ; irregular light coloured areas then appear scattered over the grain and give it a distinctly moth-eaten appearance (Plate II, fig. 6).

The inheritance of this character has not yet been worked out from crosses of the pure mottled types but, from the results of two F_2 families in which this type was present, it appears to be simply recessive to even-colouring. In the two families concerned six groups occurred, *viz.*, dark, medium and ripening for both gold and furrows. In all groups both *even* and *mottled* occurred in about the same proportion, the total figures showing a *3 : 1* ratio as below :—

	Even		Mottled
No. 2569	611		230
„ 2573	981		330
Total	1,592		560
3 : 1	*1,614*	:	*538*

Further work on crosses between pure types is necessary to confirm these results but, provisionally, an even-colouring factor E may be held responsible for the prevention of mottling.

2. SHAPE OF GRAIN.

One of the most striking features of cultivated rice is the enormous variation shown by different varieties in the size and shape of the grain. There must be a large number of factors concerned in this variation and their analysis is likely to prove a matter of some difficulty. Generally speaking, as is very common in such cases, a cross between widely different types gives an F_1 somewhere intermediate and an F_2 comprising a complicated series of overlapping types that result in a more or less continuous variation between widely different extremes.

In two cases, however, single-factor variations have been found. One of these, connected with a dwarf habit, is described later. The other, with which the present description is concerned, is closely connected with the factor G that has been dealt with above.

It will be seen from Plate I that the *ripening gold* and *ripening furrows* types, figs. 1 and 4, are distinctly long and narrow, *fine*, compared with the *dark gold* and *dark furrows* types, figs. 2 and 5, that are shorter and broader, *coarse*. This distinction has been noted in all the varieties so far seen that show these colourings. In other words $G\ G$ varieties are *coarse* and $g\ g$

varieties are *fine*. The distinction is more a matter of the relation between length and breadth of the grain than of absolute measurements, though very commonly *G G* varieties are both shorter and broader than *g g* varieties.

Crosses between the two types give an intermediate F_1 and an F_2 comprising three groups—*coarse G G : intermediate G g : fine g g* in a *1 : 2 : 1* ratio.

The connection was first noted definitely in a family, No. 1247 N, giving a *3 : 1* ratio of *dark and medium gold : ripening gold*. Grain measurements were made for each plant and the averages for the two groups were as follows :—

	No. of plants	Length mm.	Breadth mm.	$\frac{\text{Length}}{\text{Breadth}}$
Dark and medium gold ..	1182	8·45	3·00	2·8
Ripening gold	378	8·85	2·75	3·2

In all cases, both here and in later figures, the *grain* measured was the ordinary grain of *paddy* that breaks off on threshing. This comprises the rice grain enclosed in the inner glumes, with the receptacle and outer glumes attached at the base (Plate III, figs. 1–6). It was found that the measurement of three of the end grains from a well-developed panicle was sufficiently accurate for each plant and, except where otherwise stated, the figures that follow are based on such measurements.

Further families from the above lot confirmed these results : pure dark golds were coarse, pure ripening golds were fine, and splitting lots gave three groups—coarse dark gold, intermediate medium gold and fine ripening gold. The averages of several pure lots are shown in Table VIII compared with one of the splitting lots. The average of a number of natural crosses, occurring as medium golds in the pure ripening gold lots, is also shown.

TABLE VIII.

Length and breadth of grain and factor G.

Ref. No.	Character of parent	Dark gold G G		Medium gold G g		Ripening gold g g	
		L.	B.	L.	B.	L.	B.
1794 N	Dark gold	8·3	3·0	..	..	..	..
1795 N	do.	8·3	2·9	..	..	..	..
1796 N	do.	7·8	2·9	..	..	..	..
1789 N	Ripening gold	..	..	..	..	8·8	2·6
1790 N	do.	..	..	..	..	8·9	2·6
1791 N	do.	..	..	..	..	9·0	2·7
1792 N	do.	..	..	..	..	8·9	2·7
1800 N	Medium gold	8·4	3·0	8·7	2·9	9·1	2·7
Crosses	(36 plants)	..	..	8·6	2·9	..	..

N.B. *Measurements are in millimetres.*

Since this connection was first noted it has been found to occur constantly in all families segregating for *G*, irrespective of whether the character concerned was dark gold, dark furrows, or both together. In some of the families of which results have been recorded it appears that other factors also have been concerned in the determination of size and, to some extent, shape. Thus the measurements of different families of the same original cross show distinct variations. Conditions of growth undoubtedly affect the size of grain, and possibly also the shape to some extent. This increases the difficulties met with in dealing with such characters ; thus one season's measurements cannot be compared directly with those of another. Some of the differences met with, however, are too large and too various to admit of this as the whole explanation.

This will be seen from Table IX where the results are given of six families, all from the same original cross and splitting in the same manner. They were grown side by side under uniform treatment. The average length and breadth of grain is given for each group, together with the value L/B . It will be seen that the variation from family to family is considerable, though the usual connection between *G* and *shape* still holds for any one family.

Table IX.

Ref. No.	Dark furrows G G			Medium furrows G g			Ripening furrows g g		
	L.	B.	L/B.	L.	B.	L/B.	L.	B.	L/B.
2223 N ..	8·4	3·0	**2·8**	8·5	2·9	**3·0**	8·9	2·6	**3·4**
2225 N ..	8·2	2·8	**2·9**	8·4	2·7	**3·1**	8·5	2·4	**3·5**
2229 N ..	8·4	2·9	**2·9**	8·6	2·8	**3·1**	9·0	2·5	**3·6**
2230 N ..	8·5	2·9	**2·9**	8·7	2·7	**3·2**	9·2	2·5	**3·7**
2236 N ..	8·6	2·6	**3·3**	8·8	2·6	**3·4**	8·9	2·1	**4·2**
2241 N ..	8·4	2·6	**3·2**	8·4	2·5	**3·4**	8·5	2·3	**3·7**

N.B. *Measurements are in millimetres.*

Several crosses between pure types have now been made for further exact work. One of these, No. 2584, *dark gold* × *ripening gold*, has given the results shown in Table X. For the parents and F_1 100 grains each were measured ; in F_2 10 grains were measured for each of 100 plants in each group. The table shows the range of variation in length, breadth and length ÷ breadth of each group in F_2, together with the averages.

TABLE X.

Grain measurements of No. 2584, F_2.

Dark gold × Ripening gold.

Length mm.	Number of plants: Dark gold	Number of plants: Medium gold	Number of plants: Ripening gold
8·2	13	2	..
8·4	43	13	..
8·6	32	40	2
8·8	11	36	17
9·0	1	8	39
9·2	..	1	33
9·4	..	..	8
9·6	..	..	1
Average length	8·43	8·63	9·10
Breadth mm.			
2·1	..	..	1
2·2	..	..	17
2·3	..	..	39
2·4	..	3	40
2·5	..	24	3
2·6	18	50	..
2·7	67	23	..
2·8	15	..	..
Average breadth	2·70	2·59	2·33

Length / Breadth	Number of plants: Dark gold	Number of plants: Medium gold	Number of plants: Ripening gold
3·0	22	1	..
3·2	67	24	..
3·4	11	62	..
3·6	..	11	7
3·8	..	2	42
4·0	..	..	33
4·2	..	..	16
4·4	..	..	2
Average L/B	3·14	3·34	3·88

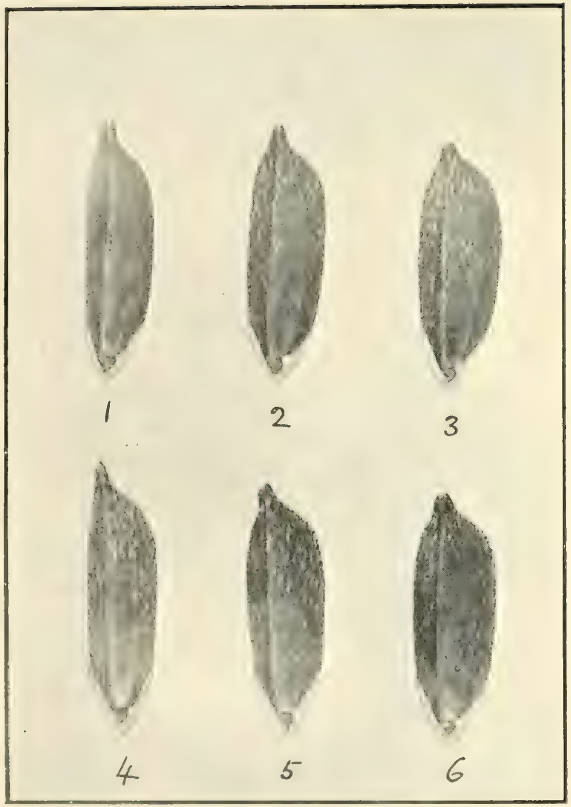
Averages for parents and F_1.

	Dark gold parent	F_1	Ripening gold parent
Length	8·30	8·72	8·75
Breadth	2·75	2·60	2·27
L/B	3·00	3·36	3·85

It will be seen that the homozygous groups in F_2 are quite distinct in shape ; thus, whilst there is some overlapping in length, the groups are quite separate as regards breadth and length ÷ breadth. They do not reproduce very exactly the measurements of the two parents. By an oversight only the actual parent plants of the cross were measured. Had the average of a number of plants of each parental type been taken, it is possible that a closer approximation would have resulted. This point will probably be settled in future generations.

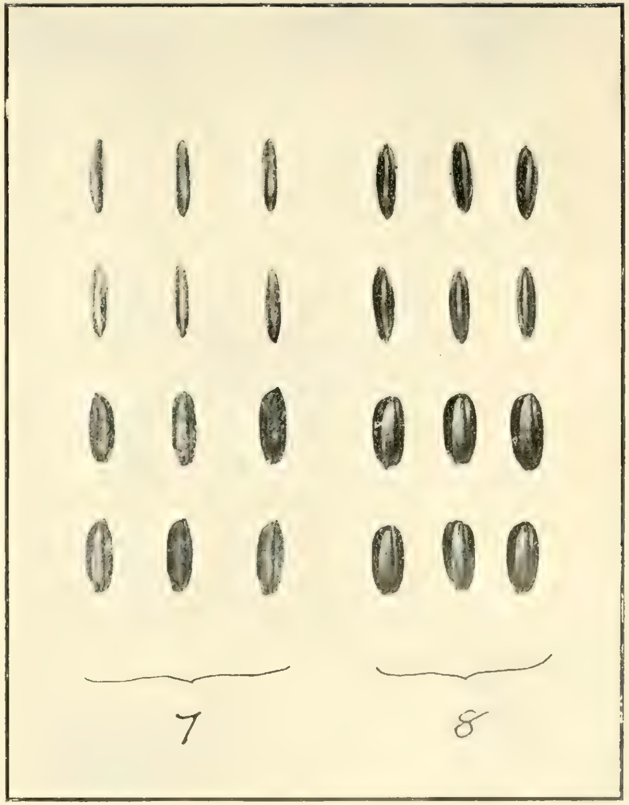
In Plate III, figs. 1–6, photographs are given of single grains from the two parents, F_1 and the three groups of F_2 of the above cross. The grains were selected so that each corresponds in its measurements with the average of the group from which it was taken.

PLATE III.



Grain-shape, Cross No. 2584.

1, Parent, ripening gold, *fine*.
2, F_1 medium gold, *intermediate*.
3, Parent, dark gold, *coarse*.
4, F_2 ripening gold, *fine*,
5, F_2 medium gold, *intermediate*.
6, F_2 dark gold, *coarse*.



Grain development

7, Gold rice, *thin*.
8, Red rice, *plump*.

From No. 2573, F_2.

A further point of interest, and one of considerable economic importance, is that the *weight* of the grain varies with its *shape*, the coarser types being heavier. This has been recorded in several families of which one, No. 2584, for which measurements are given in Table X, gave the following figures :—

	WEIGHT OF 100 GRAINS IN GRAMMES		
	Dark gold	Medium gold	Ripening gold
Dark gold parent ..	2·145	..	..
Ripening gold parent .	..	..	1·755
F_1 ..	..	2·050	..
F_2 ..	2·144	2·075	1·910

The figures for F_2 represent the averages of 100 plants in each group ; for F_1 and the parents only the single plants concerned were weighed.

It is not possible at present to give a definite interpretation of the connection between grain shape and the factor *G*. That a very close connection exists is obvious from the results given. Coarseness may be due to a separate factor closely linked with *G*, or, on the other hand, the factor *G* itself may be the determining factor. Further work, including a search for cross-over types, is necessary before a definite statement can be made.

3. A DWARF HABIT.

Reference has already been made to a single-factor variation in grain-shape that is connected with a *dwarf* habit. The variety that introduced this habit is strikingly different from ordinary varieties in many important points and is the only one of its kind that has been seen. It was obtained, through the courtesy of Mr. McKerral, Deputy Director of Agriculture, Lower Burma, from the Government Agricultural Station, Hmawbi, Burma.

The plant is shortened and thickened in all its parts and forms a very stiff erect clump. The leaf is coarse and rough, much broader than that of any ordinary variety and quite erect. The panicle is very compact, cigar-shaped and erect, due to its short stiff branches being closely pressed together. The grain is short and rounded.

This dwarf variety, E. B. 304, has been grown for several seasons at Coimbatore and in one of its generations a natural cross appeared. This cross was normal in every respect and showed no trace of the dwarf characters described above. In F_2 the whole of the dwarf characters segregated together and a simple *3 : 1* ratio of *normal : dwarf* was the result, the actual numbers being *1248 : 391*. The dwarfs were absolutely distinct from the normals and, apart from a slight increase in vigour, were identical with the dwarf parent in all its peculiarities. The normals were entirely normal and showed no trace of any of the dwarf characters. Plate IV shows photographs of the two types appearing in F_2.

It is obvious that a single factor is concerned in spite of the great differences in a number of parts of the plant.

Certain colour characters and a glutinous rice character introduced into the cross showed the male parent to be a type, E. B. 303, that was growing alongside the dwarf variety in the season when the cross occurred. It is possible, therefore, in giving certain measurements for F_2, to compare these with the corresponding measurements of both parents.

Table XI shows the range of variation in height of the normal and dwarf groups of F_2 together with that of a certain number of plants of both parents. The height measurement was taken from ground level to the top of the heads gathered together in a bunch.

TABLE XI.

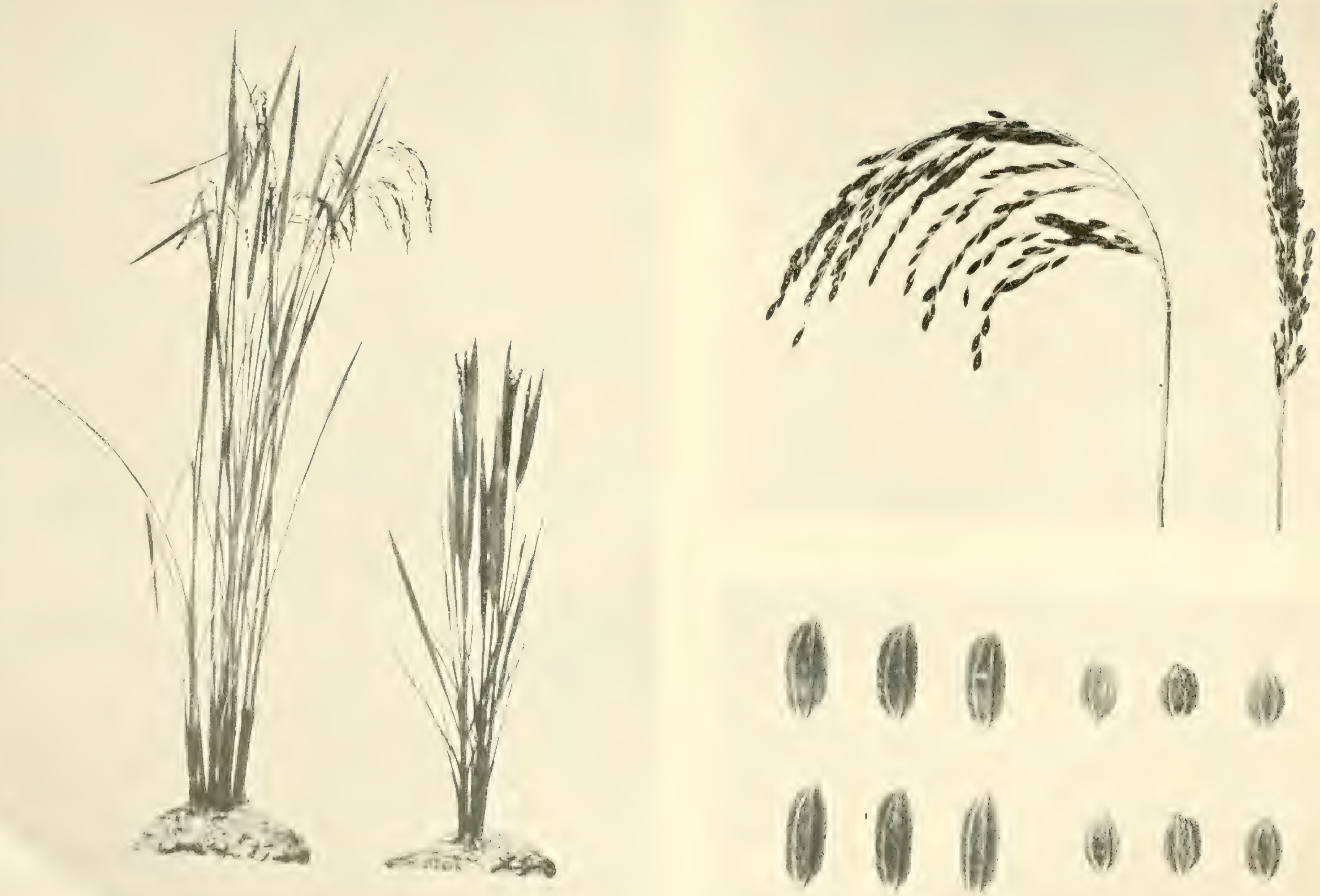
Segregation for height in F_2 No. 2666 *N.*

Normal × Dwarf.

Height in inches	NUMBER OF PLANTS			
	F_2		Parents	
	Normal	Dwarf	E. B. 303 normal	E. B. 304 dwarf
26	..	14	..	10
30	..	166	..	30
34	..	186	..	..
38	..	25	..	..
42	10	..	5	..
46	165	..	26	..
50	533	..	51	..
54	429	..	42	..
58	106	..	7	..
62	5	..	..	..
Average height	50·5″	31·2″	49·7″	27·9″

The figures show the very distinct nature of the segregation, the shortest of the normal group being taller than the tallest dwarfs.

PLATE IV.



Normal. Dwarf. Normal. Dwarf.

FROM No. 2666, F_2.

Several other measurements were made, including length and breadth of leaf and of grain. The leaf below the flag on three good tillers was measured and the average taken for each plant. There was no overlapping of the two groups as regards breadth of leaf, all the dwarfs being broader than the broadest normal. In length there was some overlapping but the averages for the dwarf and normal groups showed considerable difference. In grain-measurements there was no appreciable difference in breadth but a large difference, with no overlapping, in length. The figures below show the averages for the two groups, together with the parents, of the three measurements showing the greatest differences.

	F_2		PARENTS	
	Normal	Dwarf	Normal	Dwarf
Length of leaf, cm. ..	46·1	34·6	45·7	38·4
Breadth ,, ,, ..	1·11	1·70	1·11	1·74
Length of grain, mm. ..	9·77	6·50	9·28	6·36

Other crosses with the dwarf type have now been made for further verification with exact measurements.

4. RICE COLOUR.

Red rice.

It has already been shown, Part I, p. 100, that in many cases *red rice* is simply dominant to *white* giving a *3 : 1* ratio in F_2.

Mention was also made, p. 103, of a family, No. 617 N, that had given a *9 : 7* ratio of *red : white*, followed by a series of varying ratios in a later generation. No explanation of these varying ratios has yet been discovered, though two further generations, comprising a large number of families, have been grown. It appears, however, that at least two factors are concerned. Thus all lots from a family giving approximately a *3 : 1* ratio gave ratios ranging round *3 : 1* in the next generation, whereas lots from families giving a *9 : 7* ratio gave a wide range of ratios varying from *9 : 3·3* to *9 : 11.* Further investigation into the possible causes of such varying ratios is necessary before any explanation can be given.

Red rice, grey-brown rice and anthocyan pigmentation.

The relation between *red* and *grey-brown* rice was considered in Part I, p. 101, and later results, with their probable explanation, were given in a postscript. It was shown that, in the families there concerned, the *red rice* colour only developed in plants with *purple pigmentation*, its place being taken by *grey-brown* in *unpigmented* plants. It was suggested that the pigmentation factor concerned was necessary, in addition to a red rice factor, for the production of red rice, and that in its absence the red rice factor produced only grey-brown. The existence of unpigmented varieties with red rice was explained on the assumption that the pigmentation factor lacking in such varieties was different from that lacking in the families under consideration. This theory has now been confirmed by the results of certain crosses.

It has already been shown, Part I, p. 88, that the presence of two factors is necessary for the production of purple (anthocyan) pigmentation. These factors are denoted by *A* and *N*, the red rice factor by *R*, in the description that follows.

Taking *A* as the pigmentation factor connected with rice colour, *A R* will be *red*, *a R* will be *grey-brown*. Thus the *9 : 3 : 3 : 1* ratio, made up of *3 : 1*, *red : white*, in the pigmented group and *3 : 1*, *grey-brown : white*, in the unpigmented group, as shown by Table XXI in the postcript of Part I, is the expected result from a parent of the constitution *A a N N R r*. The simple *3 : 1* ratio of *pigmented, red : unpigmented, grey-brown* is the result from *A a N N R R*.

An *unpigmented, grey-brown*, *a a N N R R*, from the latter type of segregation, was crossed with a *pigmented, white* variety, *A A N N r r*, and gave a *pigmented, red* F_1, *A a N N R r*. In F_2 the expected *9 : 3 : 3 : 1* ratio resulted, four families giving the following figures :—

	Pigmented		Unpigmented	
	Red A N R	White A N r	Grey-brown a N R	White a N r
Nos. 1512-1515	1,785	602	587	184
9 : 3 : 3 : 1	*1,776*	: *592*	: *592*	: *197*

A more interesting cross was between the same *unpigmented*, *grey-brown a a N N R R*, and an *unpigmented*, *white* of the constitution

AA n n r r. The latter was selected from a family that had given unpigmented plants with red rice, thus showing that the pigmentation factor lacking must be *N*. F_1 was *pigmented, red,* as expected from the constitution *A a N n R r*. In F_2 five groups appeared as shown below. The figures are not as near as could be desired to expectation but there is no doubt that they represent the ratio shown.

	PIGMENTED		UNPIGMENTED		
	Red A N R	White A N r	Red A n R	Grey-brown $a\begin{pmatrix}N\\n\end{pmatrix}R$	White $\begin{pmatrix}A\ n\\a\ N\\a\ n\end{pmatrix}r$
No. 2508 ..	283	119	108	129	85
27 : 9 : 9 : 12 : 7 ..	*305* :	*102* :	*102* :	*136* :	*79*

These results definitely confirm the above theory regarding the nature of grey-brown rice and also afford additional confirmation of the existence of two factors necessary for the production of anthocyan pigmentation.

Red rice and golden rice.

An account has already been given above of the factor *I* which inhibits gold in the internode and changes any form of gold in the glumes to a corresponding form of dark furrows. It appears that this factor also is necessary for the production of red rice by the factor *R*. In the absence of *I*, that is to say, in all types with *golden glumes or internode,* the factor *R* produces *golden rice.* All *red-riced* plants so far seen have shown some form of *dark furrows* colouring in the glumes. The same applies to the various shades of light reddish rice that are common. This colouring is only produced in dark furrows types ; in golden types it is replaced by a yellowish or cream colour.

At the time of ripening golden rice is very easily distinguishable from red, as shown in Plate V, figs. 1 and 2. After keeping for some time much of the yellow colour disappears and the rice becomes duller and more brown. At this stage, if seen casually, it might be mistaken for red though the two are still separable with certainty.

Golden rice has occurred in a large number of families showing segregation for *I* in the presence of *R*. In all cases the red rice of the dark furrows group has been replaced by golden rice in the gold-glumed group. An example of this is seen in the results from a cross between *dark furrows, red rice* and *ripening gold, yellowish rice.* F_1 was *dark furrows, red rice* and two F_2 families gave the following results :—

	Furrows types		*Gold* types	
	Red	Slightly reddish	Gold	Yellowish
Nos. 2573 & 2569	1,214	391	401	146
9 : 3 : 3 : 1 ..	*1,210* :	*403* :	*403* :	*134*

From natural crosses giving similar results to the above several families, raised from red-riced F_2 plants, have given a simple *3 : 1* ratio of *dark furrows red rice : gold glumes, gold rice.*

Golden rice and undeveloped grain.

In all families in which golden rice has occurred the grain of this type has been very poorly developed. Setting appears to be normal but the rice grain is never properly filled out and frequently shrivels some time before it is fully grown. Other types of rice occurring in the same family are always quite normally developed. In Plate III are given photographs of a few typical grains of gold and red rice, from No. 2573 F_2, showing the poor development of the gold rice as compared with the red.

Grain weighments have been made in this family and the gold rice falls considerably below other groups. Weighments were made of the unhusked *paddy* grain as this was required for seed purposes later. The family was splitting for the factor *G* and this introduced a complication owing to the connection between this factor and grain shape and weight that has already been noticed. For this reason average weights are given for each of the twelve groups appearing. For each group 40 plants, 100 grains each, were weighed, except where otherwise noted. The weights in grammes of 100 grains were as follows :—

	Furrows types		*Gold* types	
	Red R I	Sl. reddish r I	Gold R i	Yellowish r i
Coarse, *G G* ..	2·250	2·219	1·695	2·193 *
Medium, *G g* ..	2·182	2·142	1·721	2·113
Fine, *g g* ..	1·974	1·917	1·556	1·868 †
Average ..	2·135	2·093	1·657	2·058

* 6 *plants only.* † 13 *plants only.*

The falling-off in weight of all three gold rice groups, as compared with the others, is very obvious. No explanation of this behaviour can be offered at present. In both parents the grain was perfectly normally developed.

Purple rice.

In a few, rather uncommon, varieties the colour of the rice is very dark purple. There is some variation in the depth of colour in different varieties, some being almost black (Plate V, fig. 3), and others rather lighter, with a reddish or brownish tinge on one side (Plate V, fig. 4). All the varieties seen with purple rice have been glutinous types, mostly from Burma. There is, however, no genetic connection between the purple colour and glutinous rice.

Purple rice is dominant to white and gives a simple *3 : 1* ratio of *purple : white* in F_2. The total figures for a large number of families are given below. The purples are somewhat in excess but the figures undoubtedly represent a *3 : 1* ratio.

	Purple rice		*White rice*
54 families	17,850		5,557
Calculated 3 : 1	*17,555*	*:*	*5,852*

The main purple rice character is obviously due to a single factor. It appears, however, that there are other factors affecting the depth of the purple colouring.

The F_1 of the darkest type of *purple* × *white*, though showing some variation, is always lighter in colour than the purple parent, especially on the dorsal side at the lower end of the grain, and shows a distinct brownish tinge (Plate V, fig. 5). In F_2 the purple group shows considerable variation, ranging from dark purple to a type where the purple is very considerably reduced and a definite brownish tinge appears. It is quite impossible to separate distinct groups as the variation is practically continuous.

In F_3 the darkest types breed true for purple though the very dark colour of the purple parent is rarely reproduced, the majority being rather lighter and slightly brownish, resembling the lighter purple varieties mentioned above. The lighter types of F_2 purples are mostly heterozygous, showing the same type of segregation as occurs in F_2, though some distinctly light types have been found to breed true.

There is no connection between the main purple rice factor *P* and the red rice factor *R* since white rice arises in F_2 from *purple* × *red*. F_1 is *purple red* since the red colour shows through where the purple is reduced (Plate V, fig. 6). In F_2 a *12 : 3 : 1* ratio of *purple : red : white* is obtained as shown by the following figures :—

	Purple P R + P r	Red p R	White p r
22 families	4,540	1,215	449
Calculated 12 : 3 : 1 ..	*4,653* :	*1,163* :	*388*

The purple group is a very mixed lot for the same variation exists as described for F_2 of the purple white cross and, in addition, various degrees of purple-red appear. Some of the latter, where the purple is reduced to the greatest extent, nearly approach ordinary red though they are separable in well-developed grain.

Purple F_2 plants give four types of family in F_3—*pure purples*, *3 : 1* ratios of *purple : white*, *3 : 1* ratios of *purple : red*, and the same as F_2 again. Some of the pure purples show considerable reduction of the purple colouring, as noted above in the purple × white lots, and in such cases the *P P R R* type appears as purple-red like the F_1 *P p R r*.

It may be noted here that the factor *P* falls into the same linkage group as *L*, *G*, *S* and *A*, the factors responsible for purple colouring in the internode, glumes, stigma and axil, as described in Part I, pp. 91–97. Several other factors have also been found to fall into the same group and their relations will form the subject of a future paper.

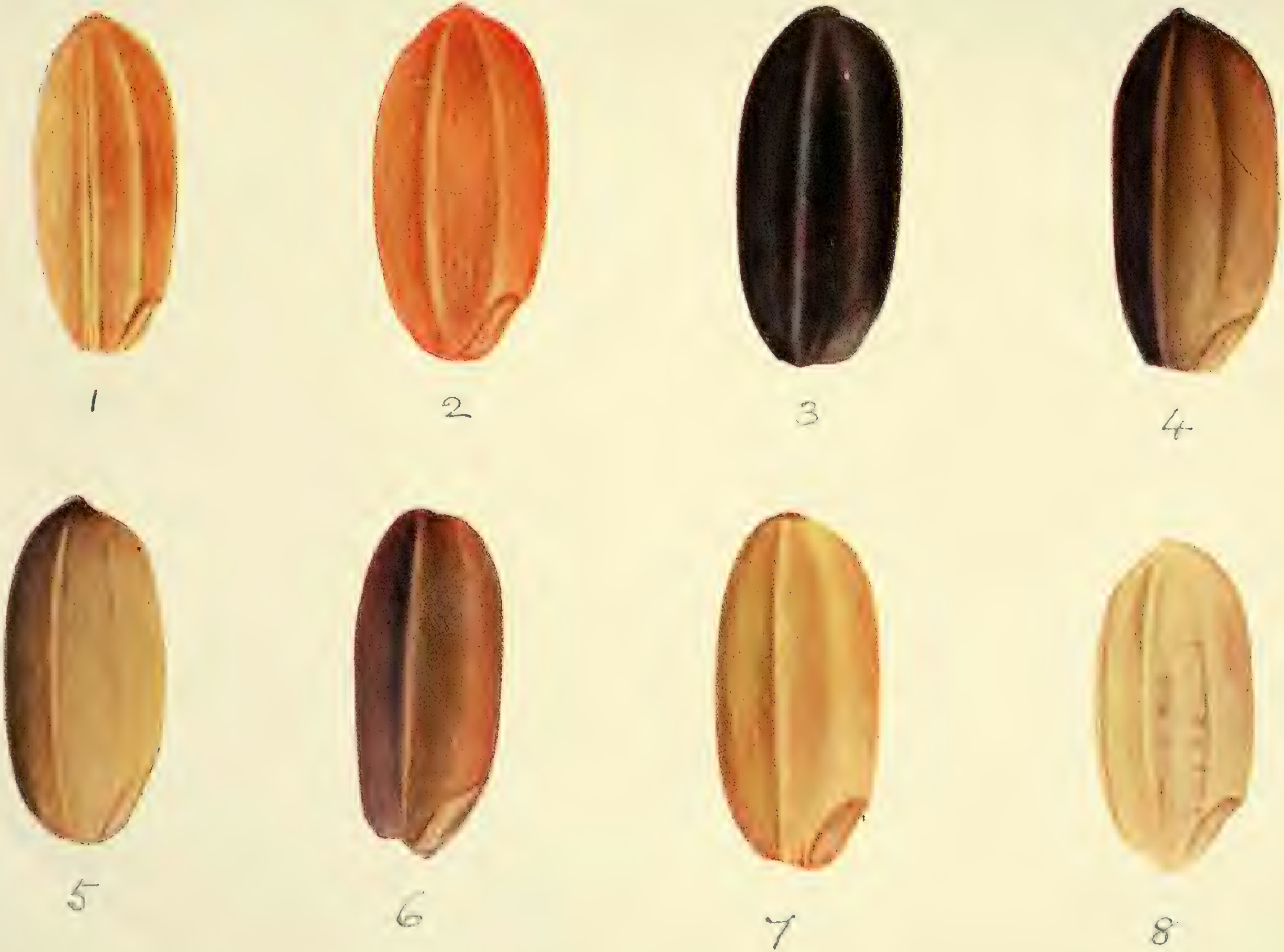
Purple and brown rice.

Just as the pigmentation factor *A* is necessary in the production of red rice so also it is necessary in the production of purple rice. In its absence the factor *P* produces *brown* rice (Plate V, fig. 7), corresponding to the *grey-brown* rice of the factor *R* (fig. 8).

This behaviour has not been worked out in detail, as in the case of grey-brown rice, but is sufficiently evident from the results of a natural cross that proved to be of the constitution *P p R r A a N n*. F_2 gave a *9 : 7* ratio of *pigmented : unpigmented*. The former group comprised *purple*, *red* and *white* and the same three types, together with *brown* and *grey-brown*, occurred in the unpigmented group.

Accurate counts were not made as there was some difficulty in separating the rice groups with certainty. The same difficulty was experienced in the more complicated families in F_3. The degree of ripeness affects the rice colour considerably; also, apparently, the rapidity with which maturation takes place has some effect on the degree of development of the colour. For this reason

PLATE



RICE COLOURS.

1. Gold.
2. Red.
3. Dark purple.
4. Light purple.

it is a matter of some difficulty to obtain reliable figures where a number of different types of rice colour are concerned.

Sixty F_3 families were raised from various types of F_2 plants* of the above cross and the results were in complete agreement with expectation so far as the types of segregation were concerned. The tables that follow show the types of segregation obtained from all the F_2 plants possessing the factor *P* that were carried on as parents.

In Table XII, which comprises the pigmented, purple rice parents, the types appearing in the different families are shown by a + sign under the respective headings.

TABLE XII.

Pigmented, purple rice parents.

Constitution	No. of lots	PIGMENTED			UNPIGMENTED				
		Purple P A N	Red p R A N	White p r A N	Purple P A n	Brown P a	Red p R A n	Grey-brown p R a	White p r
			9				7		
P p R r A a N n ..	7	+	+	+	+	+	+	+	+
P p R R A a N n ..	2	+	+		+	+	+	+	
P p r r A a N n ..	2	+		+	+	+			+
P P . . A a N n ..	4	+			+	+			
			3				1		
P p R r A a N N ..	3	+	+	+		+		+	+
P p r r A a N N ..	2	+		+		+			+
P p R r A A N n ..	1	+	+	+	+		+		+
P p R R A A N n ..	2	+	+		+		+		
P P . . A A N n ..	1	+			+				
			Pure						
P p R r A A N N ..	1	+	+	+					
P P . . A A N N ..	5	+							

In Table XIII families from unpigmented parents, both purple and brown rice, are shown in the same way.

---

* Selected to cover the range of variation but with no reference to their proportions in F_2.

TABLE XIII.

Unpigmented parents.

Parent	Constitution	Unpigmented					
		No. of lots	Purple P A n	Brown P a	Red p R A n	Grey-brown p R a	White p r
Purple ..	P P . . A A n n	2	+				
Do. ..	P P . . A a n n	2	+	+			
Do. ..	P p R R A A n n	1	+		+		
Do. ..	P p R R A a n n	2	+	+	+	+	
Do. ..	P p R r A a n n	2	+	+	+	+	+
Brown ..	P p R r a a . .	4		+		+	+
Do. ..	P p R R a a . .	1		+		+	
Do. ..	P P . . a a . .	1		+			

The purple rice character does not appear to be affected by the factor *I* as is the red rice character. Thus in one F_2 family segregating for *I* in the presence of *P* the plants with golden glumes showed the same purple rice colour as appeared in plants with dark furrows.

COIMBATORE:
16*th July*, 1921.

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A NEW GINGER DISEASE IN GODAVARI DISTRICT

BY

S. SUNDARARAMAN, M.A

Government Mycologist, Madras

AGRICULTURAL RESEARCH INSTITUTE, PUSA

PRINTED AND PUBLISHED FOR
THE IMPERIAL DEPARTMENT OF AGRICULTURE IN INDIA

BY
THACKER SPINK & CO., CALCUTTA
W. THACKER & CO., 2, CREED LANE, LONDON

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A NEW GINGER DISEASE IN GODAVARI DISTRICT.

BY

S. SUNDARARAMAN, M.A.,
Government Mycologist, Madras.

[Received for publication on 10th February, 1922.]

During the month of November 1920, the writer's attention was first called to this disease at Modekurru in Godavari District. The village was visited and the crop examined. It was reported that the two previous crops had suffered considerable loss. It was difficult to estimate at that time how serious the disease might prove to be. In a letter one of the garden owners stated that more than 75 per cent. of the plants were found affected by the disease.

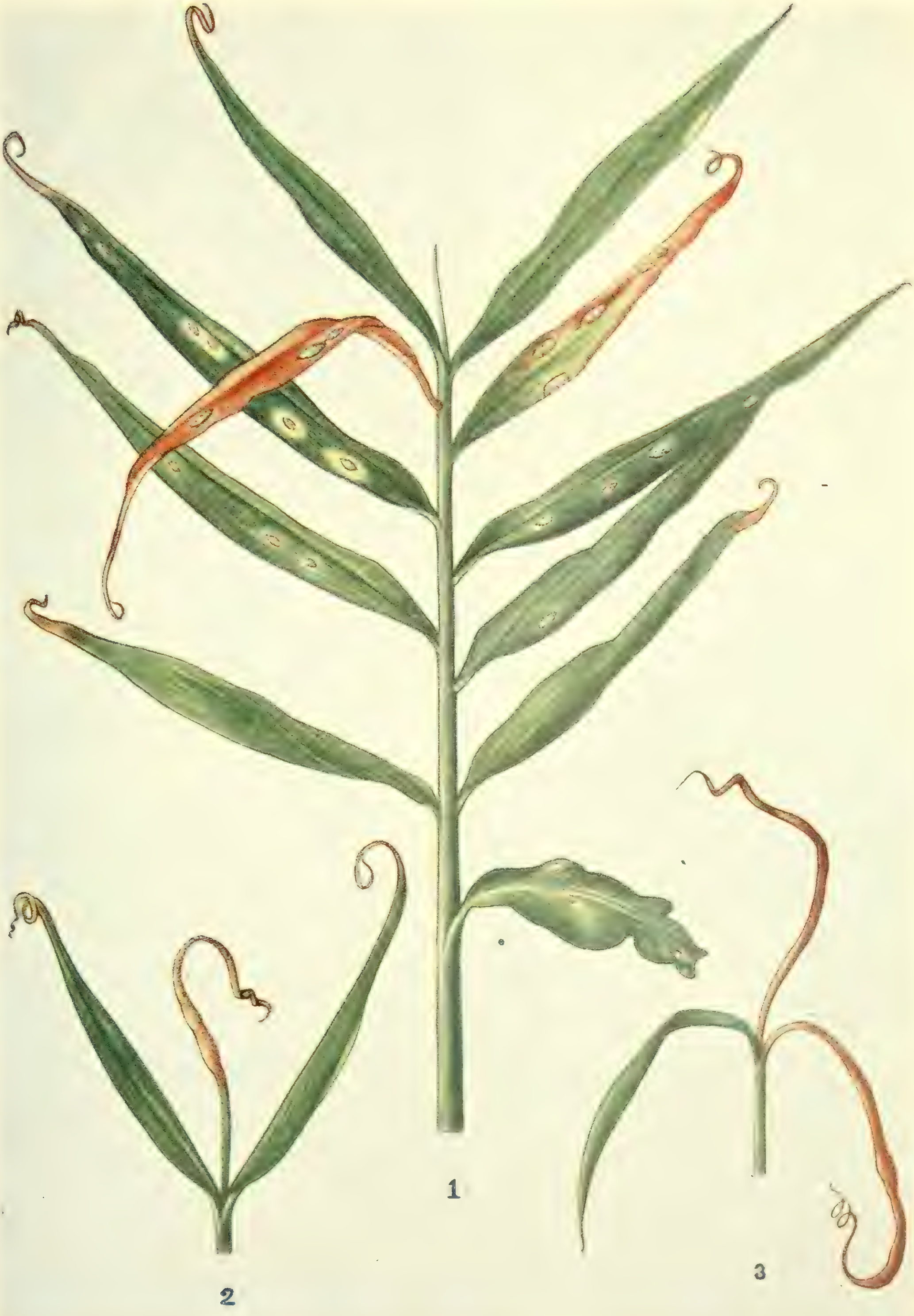
In this village and other villages in the neighbourhood ginger occupies an important place in cultivation. In almost all high level lands, every ryot grows it in small plots. It is sometimes irrigated from wells. The land is well prepared and manuring by sheep-penning is common. The rhizomes are planted in June and sometimes in the first week of July and the crop is ready for harvest from January to March. The plants occupy the ridges and are 5 to 6 inches apart in lines 1 to 1½ feet apart. When full grown the crop presents a very luxuriant appearance. It is always grown pure. In its early stages it is protected by shade. The crop under shade always looks better and the rhizomes are reported to grow bigger. Sometimes ginger is found cultivated in the midst of coconuts. In good garden lands it is raised year after year without any rotation. In this case the only preliminary treatment the land receives is crow-barring in February and subsequent levelling in June. Often the seeds are planted close, the crop is thick and there is little penetration of light and air -- conditions which favour disease when bad weather supervenes. In this district the average yield from a ten-cent plot is 4 *putties* or

2,000 lb. green ginger. The price varies from Re. 1-8 to Rs. 5 per 25 lb. The crop is thus very profitable and any disease involves much loss to the cultivator.

During the year 1920, the rainfall in August and September was very heavy, much heavier than in normal years. The disease made its appearance in August and gradually spread and grew in virulence. High humidity seemed to help the spread and progress of the disease. A few yards away from this plot there were larger areas under turmeric, which showed a severe form of leaf-spot disease caused by the fungus *Vermicularia Curcumæ*. Leaves and leaf-sheaths were so badly attacked that they got dried up, with the result that few rhizomes were formed. A few ryots attributed the disease to the manure used. A few others blamed the north winds blowing at that time. From fuller enquiries, it was clear that the disease appeared in August and gradually spread from north to south, the direction in which the wind was blowing. The disease made very rapid progress during the period of continued wet weather. A change of weather condition arrested the progress of the disease and many plants appear to have recovered.

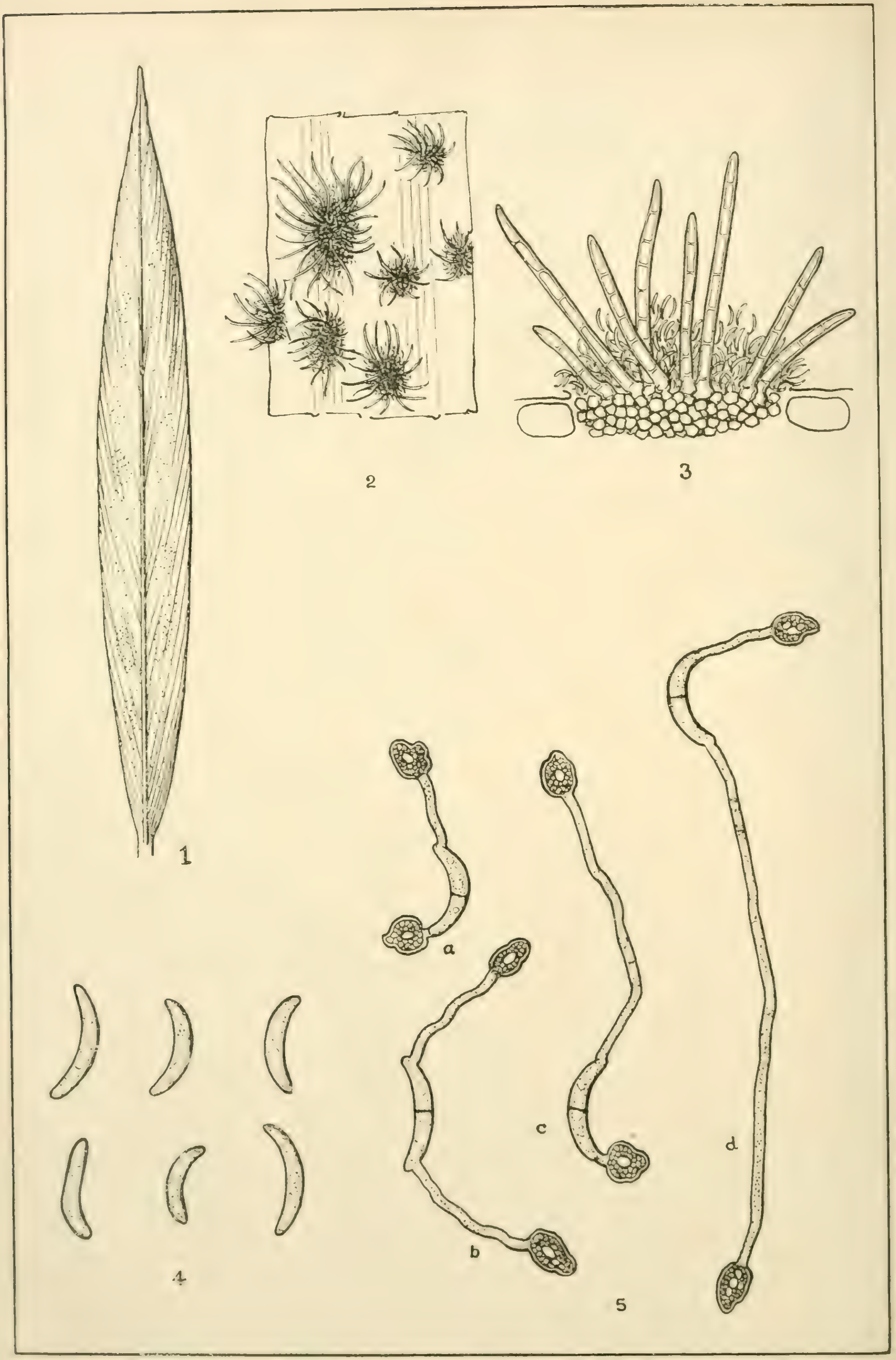
Description of the disease.

Leaves were the first to show disease symptoms. Light yellow spots both on the upper and lower surfaces were a sure sign. These were at first small, round and oval, 2-3 mm. in diameter (Plate I, fig. 1). They gradually increased in size. Later, some of them coalesced together to form large discoloured patches, and tiny black dots appeared in the centre. The tissues in the centre dried up and holes were formed. If the open leaf gets the disease, it rots and dries up (Plate I, figs. 2 & 3). The leaf-sheath and the scaly portion of the rhizomes do not escape it. In the final stages, minute dark dots appear in irregular concentric rings in the diseased region (Plate II, fig. 1). These dots consist of a stroma, with large clusters of hyphæ and masses of spores and setæ. The setæ can be seen with the help of a hand-lens (Plate II, fig. 2). When the central shoots are affected the entire surface is studded with these spots (Plate I, figs. 2 & 3). These show the fructification of the fungus. When several spots appear on the edges of the leaf, the edges roll up (Plate I, fig. 1). When the leaf-tip is affected it bends and droops down. The intensity of the disease is seen in the petioles and the scaly leaf on the rhizomes being affected. In a few instances, the lower leaves of plants show the disease while the top leaves look healthy. In certain cases the central shoot is affected and the lower leaf is free. Thus, the crop exhibits various symptoms pointing to the conclusion that these are cases of local



DISEASED GINGER PLANTS.

PLATE II.



A NEW GINGER DISEASE.

infection—infection from plant to plant favoured by conditions of moisture and atmosphere, that is, rainy weather followed by wind and moist muggy weather. The disease appears in August and seems epidemic in years of heavy rainfall. Continued rain with spells of dry weather is congenial for its development. The rains wash down the fungus spores to lower portions of the plant, and the wind carries the spores from leaf to leaf and from plant to plant. The cultivator produces conditions favourable to the disease by his thick planting which tends to make plants touch each other, not admitting light and air which are essential for healthy vigorous growth.

Effects of the disease.

The disease appears on the leaves. This is the part where the plants manufacture food. The disease makes its appearance in the growing period of the crop and at a time when the rhizomes begin to develop. As the fungus attacks directly the place where plant food is manufactured, the plants get stunted and the rhizomes do not develop. Under healthy conditions the [illegible] the crop [illegible] the plants begin to die.

Description of the fungus.

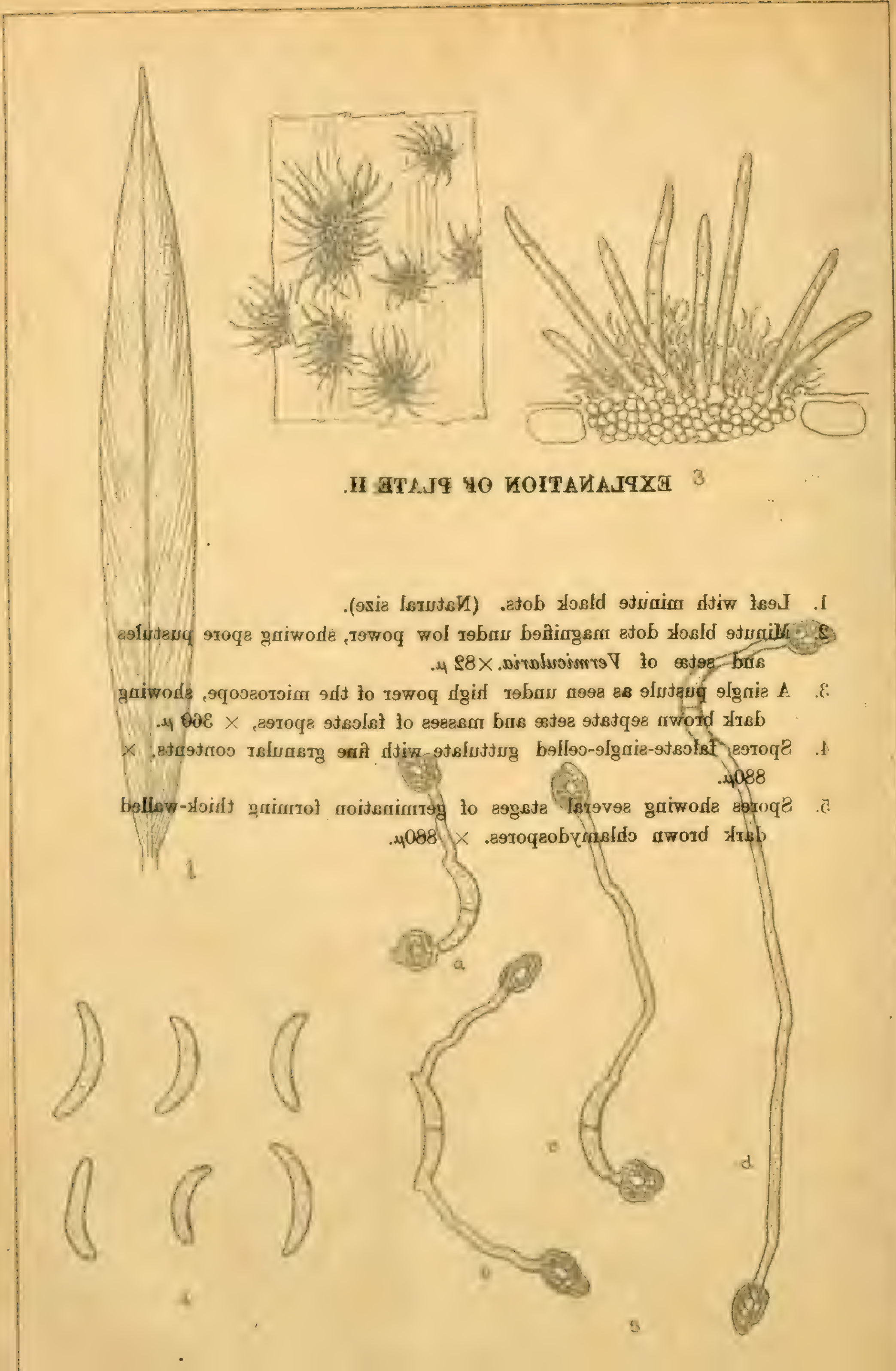
The sporodochia appear in pale yellow spots varying in size. They are [illegible] colour, [illegible] numerous, erect, dark brown, septate, 85-168 μ long (Plate II, figs. 2 & 3) ; spores, subfusoid, curved with a blunt point, hyaline, minutely guttulate, 17·5-24 μ × 3·15-4·2 μ (Plate II, fig. 4). On leaves, petioles and scale-like leaves on the rhizomes of [illegible] in Amalapur Taluk, Godavari District.

The hyphæ are hyaline and septate. They vary in diameter from 2 to 8μ. In old culture the hyphæ become light brown. The spore clusters are formed partially submerged under the epidermis but on breaking the epidermis come out to the surface, and take on the character of *Colletotrichum*, the setæ appearing to spring from the layer of sporophore (Plate II, fig. 3). The spores germinate in 4-6 hours, putting forth a germ-tube, and produce chlamydospores in 18 hours. These are formed at the end of germ-tubes (Plate II, fig. 5, a, b, c, d). Some spores form chlamydospores without the intervention of the germ-tube. The chlamydospores are sometimes divided into cells each having a germ-pore. These are either round or ovate or irregularly lobed and are generally dark-olive. When the spores begin to germinate they produce a

---

EXPLANATION OF PLATE II.

1. Leaf with minute black dots. (Natural size).
2. Minute black dots magnified under low power, showing spore pustules and setæ of *Vermicularia*. ×82 μ.
3. A single pustule as seen under high power of the microscope, showing dark brown septate setæ and masses of falcate spores, × 360 μ.
4. Spores falcate-single-celled guttulate with fine granular contents. × 880μ.
5. Spores showing several stages of germination forming thick-walled dark brown chlamydospores. × 880μ.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d
e

infection—infection from plant to plant favoured by conditions of moisture and atmosphere, that is, rainy weather followed by wind and moist muggy weather. The disease appears in August and seems epidemic in years of heavy rainfall. Continued rain with spells of dry weather is congenial for its development. The rains wash down the fungus spores to lower portions of the plant, and the wind carries the spores from leaf to leaf and from plant to plant. The cultivator produces conditions favourable to the disease by his thick planting which tends to make plants touch each other, not admitting light and air which are essential for healthy vigorous growth.

Effects of the disease.

The disease appears on the leaves. This is the part where the plants manufacture food. The disease makes its appearance in the growing period of the crop and at a time when the rhizomes begin to develop. As the fungus attacks directly the place where plant food is manufactured, the plants get stunted and the rhizomes do not develop. Under healthy conditions the crop stands in the ground from July to March but when the disease comes on, the crop has often to be lifted early before the plants begin to die.

Description of the fungus.

The sporodochia appear in pale yellow spots varying in size. They are aggregated together in dense clusters, circular to oval in outline, black in colour, 50-140 μ in diameter (Plate I, fig. 1) ; setæ numerous, erect, dark brown, septate, 85-168 μ long (Plate II, figs. 2 & 3) ; spores, subfusoid, curved with a blunt point, hyaline, minutely guttulate, 17·5-24 $\mu \times$ 3·15-4·2 μ (Plate II, fig. 4). On leaves, petioles and scale-like leaves on the rhizomes of ginger in Amalapur Taluk, Godavari District.

The hyphæ are hyaline and septate. They vary in diameter from 2 to 8μ. In old culture the hyphæ become light brown. The spore clusters are formed partially submerged under the epidermis but on breaking the epidermis come out to the surface, and take on the character of *Colletotrichum*, the setæ appearing to spring from the layer of sporophore (Plate II, fig. 3). The spores germinate in 4-6 hours, putting forth a germ-tube, and produce chlamydospores in 18 hours. These are formed at the end of germ-tubes (Plate II, fig. 5, a, b, c, d). Some spores form chlamydospores without the intervention of the germ-tube. The chlamydospores are sometimes divided into cells each having a germ-pore. These are either round or ovate or irregularly lobed and are generally dark-olive. When the spores begin to germinate they produce a septum in the centre. Sometimes the top-cell of a seta produces a hyaline hypha which bears a cluster of spores at its end.

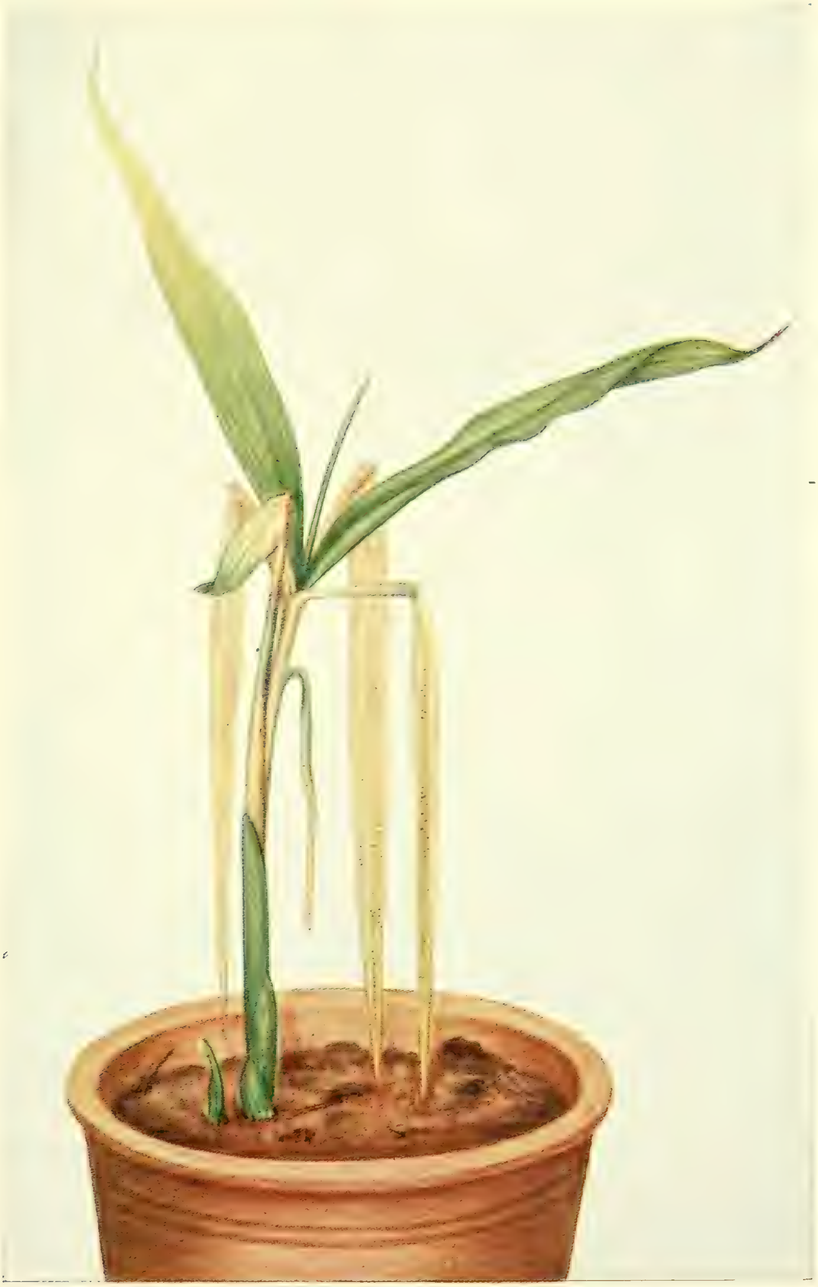
A comparative study of different characters of Vermicularia *on ginger, turmeric and chillies.*

Crop	Spore pustules	Setæ	Spores
Ginger	50 to 140 μ dia.	87·5 to 168 μ	17–24 × 3–4 μ
Chillies	70 to 120 μ ,,	70 to 145 μ	17–28 × 3–4 μ
Turmeric	35 to 160 μ ,,	56 to 102 μ	19–27 × 3–5 μ

It can be seen from the above tabular statement that there is a good deal of similarity among the ginger, chillies and turmeric *Vermicularia* in point of spore measurements. But in the measurement of spore pustules and in the formation of chlamydospores there is difference. Observing the morphological similarity of the spores of ginger *Vermicularia* to *Vermicularia* on chillies and turmeric upon which the author is now working, several cross-inoculations were carried out, but with negative results. Hence the name *Vermicularia Zingibereæ* nov. sp. is suggested.

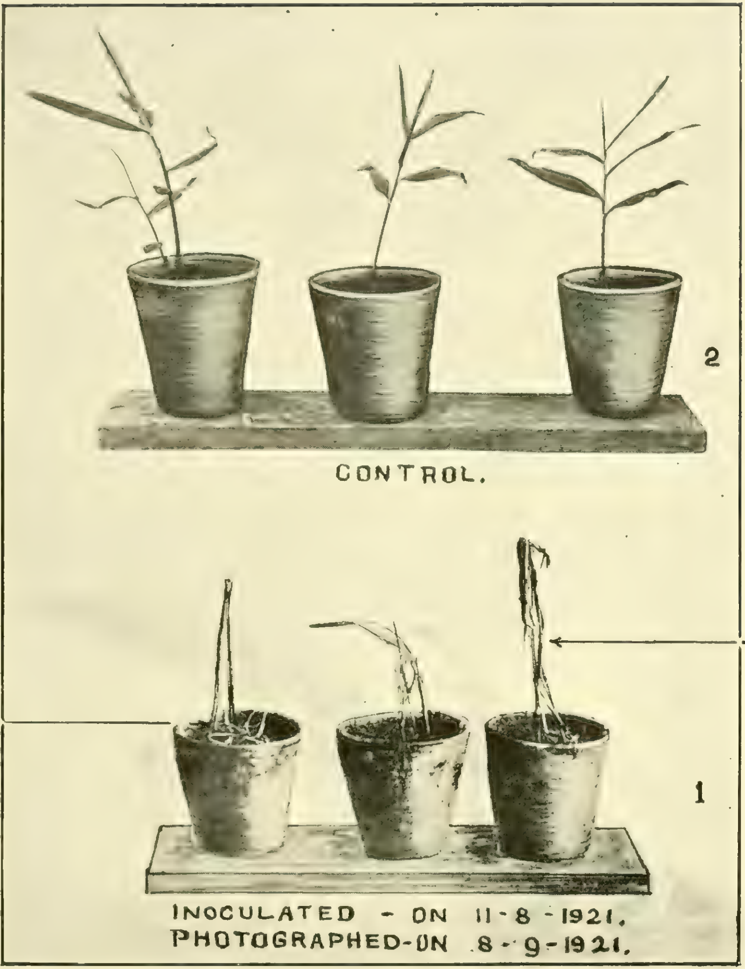
Isolation of the fungus in culture.

The fungus was brought into culture. The materials for getting this into culture were taken directly from the diseased portion of the plants. Bits of leaves showing spore formation were cut out with a pair of sterile scissors and put in melted agar tubes and transferred by the ordinary poured plate method to Petri dishes. The following day the platings were examined and single germinating spores were picked out by sterile platinum scoop and transferred to French bean and oat agar tubes. It was found that, for growth and sporulation, French bean agar furnished an excellent medium. Consequently, this was used for cultural work. The fungus grew very vigorously in French bean and oat juice agar. In 4 or 5 days dark-coloured pycnidia were formed on the surface of the agar slopes. Small, light rose-coloured droplets of thick glistening sticky fluid were seen on the surface. This was found to consist of a mass of spores.



A GINGER PLANT SHOWING EFFECT OF INOCULATION.

PLATE IV.


2
CONTROL.
1
INOCULATED - ON 11-8-1921.
PHOTOGRAPHED-ON 8-9-1921.
SHOOT COLLAPSED
HELD UP ON A SUPPORT.
OOT ROTTED.COLLAPSED
D DROPPED DOWN. LYING
THE POT

1, Ginger plants showing effects of inoculation; 2, healthy controls.

Inoculations.

Ginger plants for this experiment were raised from rhizomes obtained from a disease-free locality in Malabar, dipped in 2 per cent. formalin (*i.e.*, Schering's formalin diluted) for half an hour and then washed with distilled water. The pots used for growing the plants were new and were immersed in a 0·1 per cent. solution of corrosive sublimate and dried. The soil that was put in the pot was sterilized by heating over a fire in tin pans. Before inoculation, leaves of the plants were moistened with distilled water and spores were placed on the surface. All the plants were kept under bell-jars on platforms, and were sprayed with distilled water now and then. The plants were always in a moist atmosphere. Nine plants were used for the experiment. Six were inoculated and three were kept as control, and the same treatment was given to all. At the end of four days, discoloured spots appeared on the inoculated portion. The spots varied in size from tiny flecks to 3 mm. in diameter. Later on, the leaves began to lose colour and gradually rotting set in. Plate III shows the results of inoculation. The leaves had become rotten and dried up and pustules of the fungus appeared in large numbers. The controls remained healthy. Photographs were taken 27 days after inoculation. A glance at these will show clearly the effect of the inoculation (Plate IV, fig. 1). Every inoculation was successful and in no case did any control show any disease (Plate IV, fig. 2). These data go to establish the parasitism of the fungus beyond any doubt. Infection appears to take place through the stomata and other openings in the epidermis. Pustules are of rare occurrence upon leaves while still attached to the plants. The general development of pustules takes place upon the dead and decaying leaves and is very common in diseased fields. Inoculations conducted under drier conditions gave only negative results. The following table shows the details of the inoculations.

TABLE

Ginger plants inoculated with

Serial No.	Source of culture	Where inoculated	When inoculated	4 days after inoculation	6 days after inoculation	8 days after inoculation
1	Ginger *Vermicularia* culture got from diseased ginger leaves collected at Modekurru, sub-culture (French bean agar) of 18–7–1921 used.	Upper surface of the leaves.	11–8–1921	Colour of the inoculated leaves changing. Pale yellow spots here and there noticed.	Colour of the inoculated leaves becoming pale yellow.	Inoculated leaves yellow in colour and transparent.
2		do.	do.	do.	do.	do.
3		do.	do.	do.	do.	do.
4		Lower surface of the leaves.	do.	do.	do.	do.
5		do.	do.	No change.	Colour of leaves yellow.	do.
6		do.	do.	Colour of the inoculated leaves changing yellow.	do.	do.
7		Control	do.	Healthy	Healthy	Healthy
8		do.	do.	do.	do.	do.
9		do.	do.	do.	do.	do.

All the plants were kept under bell-jars on platforms. The platforms and the plants were sprayed

Ginger plants inoculated with

1	Ginger *Vermicularia* culture got from diseased ginger leaves collected at Modekurru, sub-culture (French bean agar) of 18–7–1921 used.	Upper surface of the leaves	11–8–1921	No change	No signs of infection.	No signs of infection.
2		do.	do.	do.	do.	Plant healthy
3		do.	do.	do.	do.	do
4		Lower surface of the leaves.	do.	do.	do.	do.
5		do.	do.	do.	do.	do.
6		do.	do.	do.	do.	do.
7		Control	do.	Healthy	Healthy	Healthy
8		do.	do.	do.	do.	do.
9		do.	do.	do.	do.	do.

All the plants were kept in big glass cases specially made for inoculation purposes. The plants were as in the previous experiment.

I.

Ginger Vermicularia (*moist conditions*).

10 days after inoculation	15 days after inoculation	20 days after inoculation	30 days after inoculation	45 days after inoculation
Tiny black dots here and there on the leaves.	Dark pycnidia developing.	Fully developed pycnidia.	Pustules fully developed with setæ. Leaves beginning to rot. Suckers coming up.	Original plant dead and fallen down. Suckers getting infected with the disease.
No change	do	Pycnidia developing.	do.	do.
do.	do.	do.	do.	do.
Tiny black dots on the leaves.	do.	do.	One sucker.	do.
No change.	Tiny black pycnidia.	do.	do.	do.
do.	do.	do.	do.	do.
Healthy	Healthy	Healthy	Healthy	Healthy
do.	do.	do.	do.	Died on account of insect bite.
do.	do.	do.	do.	Healthy

with distilled water now and then and so the plants were in a very moist atmosphere.

Ginger Vermicularia (*dry conditions*).

No change	Plant healthy	No change	No infection	No infection
do.	do.	do.	do.	do.
do.	do.	do.	do.	do.
do.	do.	do.	do.	do
do.	do.	do.	do.	do.
do.	do.	do.	do.	do.
Healthy	Healthy	Healthy	Healthy	Healthy
do.	do.	do.	do.	do.
do	do.	do.	do.	do.

sprayed with distilled water thrice a day. The atmosphere inside the glass cases was not so humid

Spraying experiments to determine the efficacy of spraying with Bordeaux mixture.

In Modekurru, Amalapur Taluk, where the ginger crop was affected by this disease, a plot of 10 cents was selected for trying the efficacy of spraying with Bordeaux mixture (5-5-50 strength) in checking the disease. The first spraying was given when the disease was fairly distributed on the plants and the second after an interval of six weeks. Before spraying, all the badly affected leaves and shoots were cut out and burnt. The following statement shows the yield and other details of the sprayed plot :—

Area of sprayed plot	No. of sprayings given	Yield		Remarks
		During the year sprayed	Previous year	
10 cents.	2 at an interval of 6 weeks.	Md. 7¼	Md. 1⅜	On account of spraying there is a clear gain of 5⅞ maunds over the previous year.

Thus from a ten cent plot there is a gain in money value of about Rs. 16 which works out at Rs. 160 per acre.

Local practice for checking the disease.

In certain plantations of this locality the usual practice to control this disease is to sprinkle quicklime on the affected plants. Enquiries show that this dusting with quicklime is imperfect and only partially prevents its spread.

Summary.

1. The leaf disease of ginger (*Zingiber officinale*) is caused by the fungus of the genus *Vermicularia* and has been reported from Amalapur Taluk, Godavari District.

2. The disease shows itself to begin with as small yellowish spots. Later on, the whole leaf turns yellow and rots, resulting in the poor development of rhizomes causing considerable loss to the ginger growers.

3. This disease makes rapid progress during a period of continued wet weather and high humidity. A change into drier conditions checks the progress of the disease and many plants recover. The results of the inoculations in the laboratory confirm this field observation.

4. The parasitism of this *Vermicularia* is definitely proved by repeated inoculations. Under moist conditions, inside bell-jars, the plants took the infection and showed disease symptoms in 15 days. But under drier conditions the fungus failed to infect the plants. The results of the inoculations confirm the field observation that the fungus made rapid progress during continued wet weather and high humidity.

5. This *Vermicularia* on ginger inoculated on chillies and turmeric failed to produce any infection.

6. The name *Vermicularia Zingibereæ* nov. sp. is suggested, owing to (*a*) the difference in the measurements of sporodochia between *Vermicularia* on ginger, turmeric and chillies, (*b*) the character of the chlamydospores and (*c*) the negative results in the cross-inoculations on chillies and turmeric.

My thanks are due to my assistants Messrs. C. Krishnan Nair and C. S. Gopalaswami Rao for their ready help.

As this paper was completed, a *Vermicularia* was noticed on Knol-Khol (*Brassica oleracea* var. *botrytis*) and cabbage (*Brassica oleracea* var. *capitata*) in the Botanic Garden, Coimbatore. This fungus is under study.

A comparative study of the *Vermicularias* on several hosts will form the subject of a separate paper.

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February 1923 Botanical Series Vol. XI, No. 10

Memoirs of the Department of Agriculture in India

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PART I

(DISEASES OF *ZEA MAYS* AND *SORGHUM VULGARE* CAUSED BY SPECIES OF *HELMINTHOSPORIUM*)

BY

M. MITRA, M. Sc

First Assistant to the Imperial Mycologist

AGRICULTURAL RESEARCH INSTITUTE, PUSA

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THE IMPERIAL DEPARTMENT OF AGRICULTURE IN INDIA

BY

THACKER, SPINK & CO., CALCUTTA
W. THACKER & CO., 2, CREED LANE, LONDON

Price, Re. 1 or 1s. 4d.

EDITED BY

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HELMINTHOSPORIUM SPP. ON CEREALS AND SUGARCANE IN INDIA,

PART I.

(DISEASES OF *ZEA MAYS* AND *SORGHUM VULGARE* CAUSED BY SPECIES OF *HELMINTHOSPORIUM*.)

BY

M. MITRA, M.Sc.,
First Assistant to the Imperial Mycologist.

[Received for publication on 2nd June, 1922.]

1. Introduction.

Many species of the genus *Helminthosporium* are common parasites on various members of the *Gramineæ*, and some species cause considerable damage to crops, *e.g.*, " stripe disease of barley " and " blight of maize " are well known in America and Europe. Saccardo in his " Sylloge Fungorum " has recorded about 30 species on various *Gramineæ* and there are a few other species which have been recorded since the publication of the last volume. In India, most of the important crops such as wheat, oats, barley, maize, great millet *(jowar)*, rice, *Eleusine*, *Panicum frumentaceum* and sugarcane are commonly attacked by species of *Helminthosporium*, and damage in some cases is considerable. They generally attack the leaves and ears and form light yellowish brown spots which in most cases coalesce and destroy the leaves.

The object of this study was to determine the range of the host plants of species parasitic on cereals and sugarcane and to ascertain whether (*a*) morphologically similar forms from different hosts vary in range of host, and (*b*) whether morphologically unlike forms have the same host range. An attempt was also made to secure the perfect stage by cultivating the species on various kinds of media.

The following species on cultivated cereals and sugarcane have been recorded from India[1]: *H. Avenæ* Br. and Cav. (oats), *H. gramineum* Rabh. and *H. teres* Sacc. (barley), *H. turcicum* Pass. (maize and great millet), *H.*

---

[1] Butler, E. J. " Fungi and Disease in Plant," 1918.

nodulosum B. and C. (*Eleusine coracana* and *E. ægyptiaca*), *H. Sacchari* Butl. (sugarcane). Beside these, *H. Oryzæ* Miyabe and Hori (rice), *H. flagelloideum* Atk. (*Panicum*) and a species on wheat have been collected from various places. The species on wheat has been brought into culture from diseased wheat plants obtained from Burma, Nagpur, Poona and Pusa, and all cultures from these four places show a good deal of variation in cultural characters and in the measurement of spores. They all give positive results when inoculated on wheat and behave alike when inoculated on other hosts. Wheat *Helminthosporium* varies in culture on the same media, and when compared with *H. teres* Sacc. found on barley, appears to be a variety of this species. *Helminthosporium* has been also observed on some wild grasses such as *Cynodon*, *Andropogon*, *Panicum* and *Eleusine indica*. A detailed account of all these will be published later on.

The present paper deals with the species on *Zea Mays* and *Sorghum vulgare* (*jowar*) and gives an account of the growth in culture on different media and results of cross-inoculation experiments on other important cereals and sugarcane. A brief summary of this has been published in the "Scientific Reports of the Agricultural Research Institute, Pusa" [1],[2].

2. Helminthosporium on Zea Mays. (H. turcicum Pass.)

Helminthosporium turcicum Pass. is an important fungus parasite of maize in Bihar and also occurs in other parts of India wherever this crop exists, except in some dry places such as the Punjab; but the damage done is not great. It attacks the leaf to a great extent and also, in a less degree, the male inflorescence. In severe attacks both the size and out-turn of grain are smaller. In the early crop, *i.e.*, before the rains, the disease is very rare. In the late crop, the disease is fairly prevalent and nearly every plant is attacked to some extent. The lower leaves of old plants and those of young plants are easily attacked and the disease is found abundantly on them, particularly during heavy rains. In some parts of the world a fungus known by the name of *H. inconspicum* C. and E. occurs on maize, but as the description agrees nearly with present species, it is probably identical with *H. turcicum* Pass. Other authors (Massee,[3] Smith,[4] Comes[5] and Pammel[6]) consider that these two species are the same fungus.

---

[1] *Scientific Reports of the Agricultural Research Institute, Pusa*, 1919-20, pp. 62-64.

[2] *Annual Report, Board of Scientific Advice for India*, 1919-20, p. 31.

[3] Massee, G. "Diseases of Cultivated Plants and Trees," 1910, p. 48.

[4] Chester and Smith. "Notes on Fungus Diseases in Delaware." *Delaware Expt. Stat. Bull.* 63.

[5] Comes. "Crittogamia Agraria," 1891, p. 409.

[6] Pammel. King and Bakke. "Two Barley Blights." *Bull. Iowa Coll. Stat.* 116, 1910.

History and distribution.

The disease was first described in 1876 in Parma by Professor Passerini as occurring on leaves of maize. Since then it has been found in the north of Italy[1] and has been recorded in South Europe, France, Russia, England, the United States of America, Japan, China,[2] the Philippine Islands, New South Wales, Queensland, and India (Bihar, Dharwar, Almora and other parts of the United Provinces, Bengal and Burma).

In the United States of America it was noticed as early as 1889. In Southern France it was observed in 1903, in India (Bihar) in 1907, in South Africa in 1912, in Australia in 1915 and in the Philippine Islands in 1919. Most writers have merely recorded the disease and have made no attempt to prove the parasitism of the fungus.

Serious damages have been recorded from various countries, *viz.*, South Africa[3], the Philippine Islands[4],[5],[6] and Italy[7]. Robinson[6] recorded it from the Philippine Islands and Otto Reinking[4],[5] described it (1919) as a common and at times very destructive disease in Philippine Islands. He says that the disease is more severe on newly introduced corns which are not acclimatized and are in a weakened condition and that native corn is not severely attacked. He found a black mould on the male inflorescence also which Saccardo has determined as *H. curvatum* but which resembles *H. turcicum* very closely.

It has been described as a serious and destructive disease in Delaware by Chester and Smith[8] (1903) and by Ducomet[9] (1903) in Southern France. Anon[10] (1915) reports it to have caused severe loss in New South Wales in localities with heavy rainfall and hot steamy weather.

It is a difficult disease to check and no proper treatment is yet known. Smith believes that spores may be able to live after passing through the alimentary canal and so manure from an animal excreta may prove a source of infection. Anon recommends rotation and use of more leguminous plants.

---

[1] Loverdo, J. "Maladies Des Cereales," p. 279, 1892.

[2] Otto Reinking. "Diseases of the Economic Plants in Southern China." *The Philippine Agriculturist*, 1919, vol. VIII, no. 4.

[3] Pole Evans. Report of Plant Pathologist and Mycologist in *Ann. Rep. S. Afr. Dept. of Agri.*, 1912-13.

[4] Otto Reinking. "Philippine Economic Plant Diseases." *The Philippine Journal of Science, A.*, vol. XIII, no. 5, 1918, p. 251.

[5] Otto Reinking. "Philippine Plant Diseases," *Phytopathology*, vol. IX, no. 3, 1919, p. 1[illegible]0.

[6] Robinson. "Corn Leaf Blight in the Philippines." *Phil. Agri. Rev.*, IV, p. 350.

[7] Loverdo, J. *loc. cit.*

[8] Chester and Smith. "Notes on Fungus Diseases in Delaware" *Delaware Expt. Stat. Bull.* on. 63.

[9] Ducomet, V. "The Browning of Maize in France." *Jour. Agri. Prat., N. Ser.*, 5 (1903), no. 16, pp. 507-511. (Only abstract seen in *Expt. St. Rec.* of U. S A.)

[10] Anon. "Blight in Maize." *Agri. Gaz. N. S. Wales*, 26 (1915), no. 5, p. 338.

THE SYMPTOMS OF THE DISEASE.

The common terms applied to this disease are " blight of maize," " blight of corn " and " leaf spots." Ducomet[1] has suggested the name of " brulure " for the disease on account of the peculiar browning burnt condition of the leaves. Maize blight, however, seems to be the most fitting term for the disease.

The disease makes its appearance, when the plant is quite young, in the form of small yellowish spots which rapidly increase in size and take on a pale brown colour. In the beginning, the infected area on the leaf is minute, roundish, and pale brown, and gradually increases in size becoming somewhat oval, the long axis of the spots being parallel to the vein. They may coalesce covering a large surface of the leaf. These spots, the breadth of which is often limited by leaf veins, later on, become somewhat translucent and to the naked eye appear like a greyish green mould on account of the conidia and conidiophores. Conidiophores and conidia are found all over the spot on both sides of the leaf but in a greater number in the central atrophied portion of the diseased area. The spots, later on, become dry and brittle and the young leaves are easily killed (Plate I, fig. 1).

In the male inflorescence the disease assumes a blackish mould-like appearance on the surface of the glumes of male spikelets. The attack is not extensive and scattered spikelets here and there are infected (Plate I, fig. 2). The mycelium ramifies within the tissues of the paleæ and the stamens.

ETIOLOGY OF THE DISEASE.

The constant association of the fungus with the disease leaves little doubt that *H. turcicum* is the cause of maize blight. Healthy plants, when inoculated, develop the disease and produce typical spores which resemble those from the field.

Leaves of maize were inoculated several times with pure culture obtained from diseased maize leaves, and it was found that the fungus had penetrated the tissues and formed spots as in nature. In some cases the infection took place within 24 hours. The plants inoculated and the controls were kept covered either with bell-jars or in moist glass chambers. It was observed that infection was rapid and vigorous on young plants and on lower leaves of mature plants. Inoculations were also made on the male inflorescence and it was noticed that all spikelets inoculated had been infected and infection had spread also on the neighbouring spikelets.

[1] Ducomet, V. " The Browning of Maize in France. " *Jour. Agri. Prat. N. Ser.*, 5 (1903), no. 16, pp. 507-11. Only abstrach seem in (*Expt. St. Rec.* of U. S. A.)

A strain from the male inflorescence of maize was also isolated and inoculations were done on the leaves and spikelets of male inflorescences. All were infected and produced the disease as in fields. In this case all inflorescences inoculated were either enclosed in glass chimney or the plants were kept in moist chambers. Controls were kept on all occasions and remained healthy.

Seedlings of maize were inoculated with a pure culture from leaves. The inoculation was done on the roots, grains and on the sheath and near the tip of the growing seedlings; within two days, in most cases, the sheath became yellowish brown and mycelium was found inside it. Later on, on examination, it was found that the mycelium had penetrated roots, pericarp and testa, and in some cases the aleurone layers of grains and also hypocotyl, etc. Most of the seedlings died on account of the disease but those which remained alive showed no growth of fungus in their tissue after some time. This shows that the fungus is capable of killing and destroying germinating grains and young seedlings but the infection is localized and does not keep pace with the growth of the host as in smut. Details of inoculations are given in the following table :—

TABLE I.

Summary of the inoculations on maize with H. turcicum *Pass.*

No.	Date	Strain used	Place inoculated	No. of inoculations	No. of successful inoculations	No. of control	Control infected	REMARKS
1	19–7–18	Maize leaf	Both sides of leaves	12	12	2	..	Five leaves were wounded and seven unwounded.
2	30–7–18	Do.	Do.	15	15	1	..	Leaves unwounded.
	5–8–18	Do.	Do.	9	9	1	..	Do.
	8–8–18	Do.	Do.	4	4	1	..	Do.
3	28–8–19	Do.	Do.	10	10	1	..	Do.
4	5–10–19	Maize male inflorescence	Do.	9	9	1	..	Do.
5	17–10–19	Do.	Male inflorescence	13	13	1	..	Do.
	19–10–19	Do.	Do.	15	15	1	..	Do.
6	19–10–19	Maize leaves	Do.	15	15	1	..	Do.
7	28–10–19	Male inflorescence	Do.	40	30	1	..	Do.
8	10–6–20	Leaf	Leaves	6	5	1	..	Do.
	7–8–20	Do.	Do.	11	5	1	..	
	10–12–20	Do.	Do.	11	10	1	..	
9	4–8–19	Do.	Seedlings	22	22	10	..	
			Total	192	174	24	..	91%

The above experiments furnish proof of the pathogenic nature of *H. turcicum* on maize leaves and inflorescence and show that the fungus on leaves and on the male inflorescence of tassel is identical.

MORPHOLOGY OF THE PARASITE.

Mycelium. The mycelium of the parasite ramifies in the tissues of the leaf and thus destroys the assimilatory apparatus of the plant, weakening the plant so that its growth is checked. The spots in which the mycelium spreads later on become dry and brittle. The mycelium consists of branched septate hyphæ, the cells of which sometimes become irregularly swollen. It is both intra- and inter-cellular. Inside the matrix the mycelium is subhyaline but where conidiophores arise it is light to olive brown colour.

In culture a light greyish green colour appears which increases gradually, becoming darker. In old cultures the cells swell up, the cell wall becoming somewhat thick and thus give rise to thick-walled cells resembling chlamydospores. Spore formation takes place in cultures 6 or 7 days old. Conidiophores bear conidia at the apex. Sometimes conidia are formed with such rapidity that at the tip of conidiophore 3 or 4 are seen. These at first sight appear to be borne in cluster, but when observed carefully it is found that only the youngest is at the tip while the rest are just below in acropetal succession. Later on, as the conidiophores elongate, the distance between the spores increases and they become more and more lateral. The conidiophore becomes bent in several places where conidia are attached, but when spores are formed vigorously one after the other no such bending is noticed. Sometimes in culture no spore formation takes place, this is especially the case when the fungus has been cultivated for a very long time in one kind of medium, but when the medium is changed, spores are formed again. On water culture or on the culture kept in a drop of water in a moist chamber abundant spore formation takes place. This method was employed to induce the fungus to form spores when it was sterile in culture tubes.

The fungus loses its parasitic nature if cultivated for a long time in culture; for instance, a fresh culture which was able to infect leaves vigorously was kept in culture for nearly a year, it was then used for inoculation but no infection took place. Fresh cultures which were exactly like the cultures of last year were again taken from the field and when inoculated gave successful results. Conidiophores are simple, septate and erect. They arise in clusters on either side of the leaf, are sometimes slightly bent above and are light brown in colour. They are 115 to 150 by 6 to 8·7μ in diameter and come out either through stomata or by directly piercing the epidermis (Plate II, figs. 18–21).

Conidia are fusiform or spindle-shaped, pointed, a little curved, light greenish brown, 4-7 septate and 75 to 125 by 18 to 24μ in diameter (Plate II, figs. 6–17). The breadth varies in different localities; for instance, spores from Almora specimens were up to 26·6μ in breadth while those from Pusa were up to 24μ only. (Almora 72 to 117·8 by 19 to 26·6μ, Malda (Bengal) 35 to 130 by 17 to 24μ. Spores from Burma and Dharwar specimens are like those from Almora.)

There is some variation with regard to the shape of spores. Typical spores of *H. turcicum* Pass. are spindle-shaped and pointed[1],[2], and these have been observed in specimens from various localities in India, such as Almora, Dharwar and Burma (Plate II, figs. 14–17), but in Pusa and Malda (Bengal) specimens, the spores are somewhat curved and narrow (Plate II, figs. 7-13). The spots on the surface of leaves are however alike in specimens collected from various localities. Though the spores in Pusa and Malda specimens are somewhat more curved yet in cultures the conidia are generally straight, spindle-shaped, and very few are curved. Conidia of the fungus from the glumes of male spikelets are a little longer and more curved than those of the leaf fungus and the fungus has been named *H. curvulum* Sacc. In the Philippines[3] it is described by this name but here in cultures it resembles the strain from the leaf and, when inoculated on the leaves, produces the same kind of spots as the leaf strain.

CULTURES.

Spore germination. When a few fresh spores are placed in a hanging drop culture, germination takes place within few hours. Germ tubes generally protrude from the ends of the spore but they have also been noticed to come from any of the middle cells of the spore (Plate II, figs. 1 and 3). In some cases the internal partition of the spore breaks down and a continuous tube is formed. Again, in a few cases, the septa disappear before the protrusion of the germ tube, while in other cases it was noticed that the septa near the ends only were disorganized (Plate II, fig. 4). Plate II, figs. 1 and 2-6 were drawn after 48 and 18 hours of sowing respectively. Detached conidiophores are also capable of germinating by giving out a tube from either end and have often been noticed to infect the leaves.

Pure cultures were obtained several times by the poured plate method or from a diseased portion of a leaf after washing it for a few minutes in a solution of corrosive sublimate in water (1 in 1000 c.c.) and then in distilled water. The washed piece of diseased leaf was transferred to an agar tube. This gave rise to an aerial growth in the tube from which a subculture was taken giving rise to pure culture.

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[1] Saccardo. *Fungi ital, a fig.* 824.

[2] Massee. "Diseases of Cultivated Plants and Trees," 1910, p. 481.

[3] Otto Reinking. "Philippine Plant Diseases." *Phytopathology*, vol. IX, no. 3, 1919, p. 140.

In the beginning spores are produced laterally on the mycelium in a large number. When young they appear to be sessile but after four or five hours' growth they are distinctly seen on a stalk which grows in length and bears many more conidia. Very often the conidia are borne at the tip of the hyphæ but after some time each of them becomes stalked, the stalk increases in size and forms two conidiophores.

On some media gemmæ-like bodies are formed and on some irregular stromatic masses, but no sclerotia or pycnidia have ever been observed.

Growth on different culture media. A large number of media were inoculated in duplicated with pure culture of *Helminthosporium*. All the media were inoculated on the same day and from the same tube. On some of the media the fungus was grown repeatedly to mark variations, if any. Tubes were kept for more than six months and in some cases for almost a year but no perfect stage of the fungus was obtained.

The following is a detailed account of the growth on various media:—

(1) *Nutrient plain agar* (+4 Fuller's scale).
(2) *Dextrose agar* (+2 ,, ,,).
(3) *Glycerine agar* (+6 ,, ,,).
(4) *French bean agar* (+8 ,, ,,). The growth is poor in all these media with very little aerial growth. Spore formation is scanty and spores are smaller than those formed on other media.

(5) *Litmus lactose agar* (+6 Fuller's scale). The growth is submerged and creeping in the beginning but later on a woolly aerial growth appears. After a few days the pinkish medium gradually turns blue. There is a good deal of spore formation, but the size of spores is smaller as on last medium. Spores are as small as 15μ in length and septation is reduced very much in most cases and in some cases spores are formed without any septum. Average spores are 45·6 to 95 by 15·2 to $22·8\mu$ in diamater. Mycelium becomes gemmate in old cultures.

(6 & 7) *Nutrient glucose agar* (+5 Fuller's scale) and *nutrient saccharose agar.* Fairly good growth of a greyish green colour. Spore formation is copious. The medium gradually becomes greenish, then dark green on account of the submerged growth, and after some days still darker. Spore formation is more copious at 20–22°C. than at 30–32°C., and at the later temperature sometimes spores of abnormal size are formed. At low temperatures growth is slow and the colour is dark greenish grey instead of light greenish grey as at 30°C. It takes about four days to fill the tube completely at 30°C., but spore formation decreases gradually with the increase of temperature, *i.e.*, when growth is increased, spore formation is less and *vice versa.* In old cultures the mycelium swells up irregularly forming gemmate.

(8) *Thaxter's hard potato agar* (+6 Fuller's scale). Copious aerial growth, the medium becomes greyish green. The growth is light green at 32°C., and dark at 22°C. In 5 or 6 days the tube is quite full and the mycelium is seen spreading on the walls of the tube. Spore formation is very free and spores are greenish brown in colour. Hyphæ light greenish brown

and the submerged mycelium is green to dark green. Spore formation is more rapid at a low temperature.

(9) *Potato juice agar* (+6 Fuller's scale). Growth not well developed. Hyphæ cells show irregular swelling here and there. Spore formation is poor. Submerged growth greenish and aerial greyish in appearance.

(10) *Coon's synthetic agar* (+8 Fuller's scale). The growth is quite good with woolly aerial mycelium of light greyish green colour. The medium also becomes greenish, spore formation is copious. Mycelium later on turns gemmate.

(11) *Cellulose agar* (+9 Fuller's scale). The growth is poor and almost submerged, of greyish colour. Spore formation fair. The colour of medium does not change.

(12) *Starch agar* (+4 Fuller's scale). Fair woolly growth, aerial hyphæ arise in clusters and grow radially. The medium turns light green. Spore formation is good.

(13) *Corn-meal agar* (+2 Fuller's scale). The growth is best on this medium. Copious, woolly, greyish green aerial growth at 30°C. The medium turns greenish and then dark green on account of submerged growth. In four days at 30°C. the growth is very profuse and the tube is almost full, the mycelium spreading on the walls of the tube. Spore formation is very good especially at a low temperature at which growth is slow. Hyphæ light olive green.

(14) *Oat-meal agar* (+2 Fuller's scale). Copious woolly aerial growth of greenish grey colour. The medium becomes dark green near the margin. The submerged growth is also greenish and then turns darker gradually. Spore formation fairly large in number and growth is more rapid at 30°C. than at 20–22°C.

(15) *Wheat-meal agar* (+2 Fuller's scale). Copious aerial growth, the mycelium spreading on the walls of the tube and lower portion of the tube quite full. Hyphæ olive green. Abundant spore formation.

(16) *Rice-meal agar* (+4 Fuller's scale). Growth good, but little less than that on corn-meal agar. Copious spore formation. Lower portion of the tube quite full with mycelium. Medium turns light green.

(17) *Barley-meal agar* (+3 Fuller's scale). Very good woolly aerial growth. Mycelium looks dark greenish and hyphæ light olive green. Abundant spore formation as on rice-meal agar. It is one of the best media for the growth and production of spores.

(18) *Jowar-meal agar* (+2 Fuller's scale). A good growth with abundant aerial mycelium. The medium gradually turns green and then dark green. Spore formation good especially at 20–22°C. Growth slow at low temperature. Spores generally are 60·8 to 140·6 by 19 to 26·6μ in diameter with 3 to 7 septa. Sometimes spores are very small and with few or no septum. Those abnormal spores are not more than 60μ in length and 10·4μ in breadth and are formed when kept at a little high temperature.

(19 & 20) *Sugarcane leaf juice agar* (+4 Fuller's scale) and *rice leaf juice agar* (+3 Fuller's scale). In both of these media growth is poor and submerged. Spore formation is scanty.

(21) *Maize leaf juice agar* (+3 Fuller's scale). Fair growth with abundance of spore formation.

(22, 23 & 24) *Sterilized maize stem, sterilized sugarcane megasse and sterilized paddy straw.* There was a good production of spores on all, especially on sterilized maize stem and sterilized paddy straw. The cultures were kept for about 7 months in each case but there was no sign of the appearance of the perfect stage.

(25) *Sterilized wheat straw.* A good deal of spore formation took place and greyish green mycelium was formed in the water at the bottom of the tube. No further growth of the fungus, however, took place though the tubes were kept for more than a year.

(*Note.* Tubes in 22–25 were kept at two temperatures, *viz.*, 22°C., and at room temperature of about 27–30°C. The growth was the same at both temperatures.)

The growth was best on corn-meal agar, barley-meal agar, rice-meal agar, Thaxter's hard potato agar and *jowar*-meal agar respectively.

EFFECT OF REACTION OF CULTURE MEDIA.

This experiment was run in duplicate on glucose medium. Twenty tubes were inoculated, two of each reaction and ranging from —15 to +30 Fuller's scale. After three days there was found to be no growth at +25 and +30 Fuller's scale ; very poor at +20, and poor at +15 and —15. It was little at -10 and +10, good at +5 and best at 0 Fuller's scale. In eight day-old culture the growth increased at +10 and +5 but comparatively little took place at 0. From the above data it is observed that this fungus prefers reaction from a neutral to an acid media ranging from 0 to +10 Fuller's scale and is best at +5 Fuller's scale though growth is more rapid at 0 in the beginning.

LONGEVITY OF THE SPORES OF MAIZE HELMINTHOSPORIUM.

Large numbers of diseased spots of maize *Helminthosporium* were cut and put in a stoppered bottle and kept for more than a year. It was noticed that up to four months ninety per cent. of the spores germinated when placed in a drop of water and incubated in a moist chamber, and up to eight months fifty per cent ; after eight months the spores rapidly lost their power of germination, and after a year they were incapable of germinating. This shows that spores can survive long enough to infect the next crop. It is quite probable that this fungus occurs on some wild grasses also and a search for them is being made.

RELATION OF PARASITE TO HOST. INFECTION AND CONIDIOPHORE PRODUCTION.

The penetration of the fungus takes place either through stomata or by directly piercing an epidermal cell (Plate III, figs. 1, 2 and 3). It can penetrate any epidermal cell, but generally it enters through subsidiary cells. The hypha from a germinating spore comes in contact with the cuticle, swells up and then sends out a narrow tube. This pierces the cuticle and may travel for a distance inside the cuticle, parallel to the outer wall of the epidermis, and after some time either enters an epidermal cell or passes through the side walls of two epidermal cells into the cells below. Sometimes it surrounds an epidermal cell, sending in branches which fill the cavity. When penetration is through a cell in contact with a guard cell, it enters the sub-stomatal space, branching freely, and becomes septate. It passes to other cells directly or through two adjacent cell-walls, *i.e.*, it is both intra- and inter-cellular. The mycelium branches and sometimes forms a net work below the epidermal layer. A few hyphæ may enter an epidermal cell to form a stromatic mass from which conidiophores arise. The development of fructifications depends upon the amount of moisture in the air and may take place after 5 or 6 days of infection.

When the fungus attacks a spikelet, the glumes, paleæ and anthers are all infected. It forms a superficial mycelium on the surface of the glumes on which a good deal of spore formation takes place.

CROSS-INOCULATION EXPERIMENTS.

Maize *Helminthosporium* was cross-inoculated on *Sorghum*, rice, wheat, oats, barley, *bajra* and sugarcane. The inoculation was done on leaves, and plants were either covered with bell-jars or placed in big glass cages where there was sufficient moisture. After infection took place the bell-jars or glass cages were removed. In every case a control was kept. The following table shows the result of experiments :—

TABLE II.

Cross-inoculations on Sorghum.

No.	Date	No. of inoculations	No. infected	Control	Control infected	REMARKS
1	30–7–18	8	4	1	..	
2	5–8–18	8	4	1	..	
3	5–8–18	2	2	1	..	The leaves were wounded
4	11–8–18	8	3	1	..	
5	18–8–18	10	6	1	..	
6	13–8–19	3	2	1	..	
7	10–6–20	11	8	..	..	
8	7–8–20	11	6	..	..	
9	11–12–20	18	14	..	..	The plants were kept in a warm and moist room.
	TOTAL	79	49	..	..	62%

Out of 79 inoculations made, 49 were successful. Controls kept showed no sign of disease. The spots formed were like those of *jowar Helminthosporium* on *jowar*. There was always a good deal of spore formation on both sides of leaves. Maize *Helminthosporium* however spreads less rapidly on *jowar* than *jowar Helminthosporium* on *jowar*.

TABLE III.

Cross-inoculations on sugarcane.

No.	Date	No. of inoculations	No. infected	Control	Control infected	REMARKS
1	5-8-18	7	4	1	..	In most cases the inoculated leaves were enclosed in a chimney, both ends of which were plugged with cotton wool so that the inoculated portions were as if in a moist chamber.
2	11-8-18	7	6	1	..	
3	18-8-18	18	10	1	..	
4	13-8-19	20	15	1	..	
5	29-8-19	10	5	1	..	
	Total	62	40	..	..	64%

Out of 62 inoculations made, 40 were successful. Maize *Helminthosporium* when inoculated on sugarcane formed small dirty straw coloured spots which increased in size when leaves were kept moist. Though maize *Helminthosporium* is capable of infecting sugarcane leaves (Plate III, figs. 4 and 5), yet they are not identical.

TABLE IV.

Cross-inoculations on rice.

No.	Date	No. of inoculations	No. infected	Control	Control infected	REMARKS
1	11-11-19	24	3	1	..	
2	25-11-19	8	2	1	..	
3	29-11-19	8	4	1	..	
4	10-6-20	10	3	1	..	
5	7-8-20	11	3	1	..	
	Total	61	15	..	..	24%

Maize *Helminthosporium* when inoculated on rice infects very few of the leaves and in these also the fungus after entering spreads very little and a spot is formed very rarely. Of 61 inoculations made, infection took place only in 15, and out of these 15 very few formed spots with conidiophores and spores.

The above table shows a low proportion of successful infection and in these cases penetration was slight. Rice may almost be considered to resist the attack of maize *Helminthosporium* though sometimes spots are formed under laboratory conditions.

TABLE V.

Cross-inoculations on bajra.

No.	Date	No. of inoculations	No. infected	Control	Control infected	REMARKS
1	29–11–19	20	..	1	..	0%

No infection on this plant took place.

TABLE VI.

Cross-inoculations on wheat.

No.	Date	No. of inoculations on leaves	No. of leaves infected	No. of inoculations on ears	No. of ears infected	Control	Control infected	REMARKS
1	19–1–20	12	12	..	..	1	..	
2	31–1–20	7	4	..	..	1	..	
3	6–2–20	10	10	..	..	1	..	
4	3–2–21	12	9	5	5	1	..	The leaves and ears of same plants were inoculated.
	Total	41	35	5	5	..	..	87%

Maize *Helminthosporium* can infect wheat easily. Out of 46 inoculations made, 40 were successful. The infected leaves became straw-coloured and the spots gradually increased in size and ultimately killed the leaves. A good deal of spore formation took place on leaves and on the ears inoculated.

TABLE VII.

Cross-inoculations on barley.

No.	Date	No. of inoculations	No. infected	Control	Control infected	REMARKS
1	19–1–20	10	5	1	..	
2	25–1–20	11	9	1	..	
3	11–4–20	8	2	1	..	
4	3–2–21	16	6	1	..	
	Total	45	22	..	..	48%

Maize *Helminthosporium* can infect barley but the infection is not so vigorous as that on wheat. Out of 45 inoculations, 21 were infected. Spores were formed on both sides of the leaves inoculated.

TABLE VIII.

Cross-inoculations on oats.

No.	Date	No. of inoculations	No. infected	Control	Control infected	REMARKS
1	19–1–20	8	0	1	..	
2	25–1–20	12	9	1	..	
3	6–2–20	12	9	1	..	
4	11–4–20	8	6	1	..	
5	3–2–20	13	3	1	..	
	Total	53	27	..	..	51%

Out of 53 inoculations made, 27 were successful. The infected spots gradually increased in size and spore formation took place. Sometimes no infection took place as on those inoculated on 19th January, 1920.

The above cross-inoculation experiments show that maize *Helminthosporium* can infect most of the cereals and sugarcane when inoculated artificially in the laboratory, *bajra* is altogether immune and rice is affected very little The following is a summary of the results of inoculations :—

Maize	91%	Sugarcane	64%	*Jowar*	62%
Wheat	87%	Oats	51%	Barley	48%
Bajra	0%	Rice	24%		

3. Melminthosporium on Jowar (Sorghum vulgare).

Jowar Helminthosporium has been collected from very few places in India and observed only in the Punjab (Amritsar and Lyallpur). The damage done by this fungus to the crop is very slight. Morphologically the fungus is identical with that on maize but it must be a different strain or variety as indicated by the cultural characters. Besides it has been observed in Bihar that this fungus is common on maize but absent on *jowar*, while in the Punjab *Helminthosporium* has been found on *jowar* and not on maize. In Bihar very often maize and *jowar* are grown as a mixed crop, and the leaves of maize are found to be diseased but not those of *jowar*. But when maize *Helminthosporium* is cross-inoculated on *jowar* in the laboratory, infection takes place. All these points, together with the difference in cultural characters, indicate that *Helminthosporium* on *jowar* is a different strain or variety of *H. turcicum* Pass.

This fungus has been reported from other countries[1], *viz.*, Egypt, China, etc., where it is not very common or injurious to this host.

There are also other species of *Helminthosporium* known on this host, such as *H. Cookie* Sacc.[2], [3], *H. Sorghi* Schw.[2], [3] and *H. geniculatum* E. and T.[4], and lastly *H. inconspicum* C. and E. which is probably the same as *H. turcicum* Pass.

THE SYMPTOMS OF THE DISEASE.

The fungus is found on leaves only and forms long, narrow spots of dirty brown or straw colour (Plate I, fig. 3). The spots are marked from the healthy tissue by a reddish ring. Generally infection takes place from the tip and extends downward either along the margin or along the midrib. Very often two or more spots are formed along the edge and these coalesce and form into one. Sometimes long elliptical or elongated spots are formed on the blade of the leaf. If these are in large number, they unite and form one irregular spot.

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[1] Butler, E. J. "Fungi and Disease in Plants," 1918.

[2] Saccardo. *Sylloge Fungorum*, vol. IV, pp. 420 and 423.

[3] Rabenhorst. *Kryptogamen Flora*, vol. IX, pp. 37 and 909.

[4] Palm Bj. "De Helminthosporium Ziekten," p. 16. *Dept. Landb. Nijv. en Handel., Meded. Lab. Plantenziekten*, no. 34 (1918). Eenige Ziekten, Waargenomen aan de tarme op Java.

ETIOLOGY OF THE DISEASE.

The parasitic nature of the fungus was proved by the following inoculation experiments.

TABLE IX.

Inoculations on the leaves of jowar *with* Helminthosporium *isolated from the diseased leaves of* jowar.

No.	Date	No. of inoculations	No. infected	Control	Control infected	REMARKS
1	19-11-19	24	19	9	..	
2	24-11-19	9	9	1	..	
3	30-1-20	6	6	1	..	
4	21-5-20	19	11	1	..	
5	10-6-20	18	14	1	..	Reisolated from No. 4 and inoculated.
6	7-8-20	10	10	1	..	
7	11-12-20	11	8	1	..	Plants kept in a moist warm room.
	Total	97	77	..	..	79%

When *jowar Helminthosporium* is inoculated on *jowar* the spots formed are typical and resemble those found in nature. The fungus was reisolated from an inoculated spot, taken into culture and again inoculated and the same symptoms and results were obtained. This proves the parasitic nature of the fungus.

MORPHOLOGY OF THE PARASITE.

The mycelium of this fungus is found in the matrix of the infected portion of the leaf. It is present also in the vessels of xylem. Very often they form stromatic masses in the epidermal cells.

Conidia are formed on both sides of the spot and conidiophores arise singly or in cluster of three or more emerging from stomata (Plate III, figs. 12–16). Conidia are 57 to 136 by 19 to 26μ in diameter (Plate III, figs. 7–11). *Jowar Helminthosporium* resembles more the *Helminthosporium* on maize from Burma, Almora and Dharwar than that from Pusa and Malda. The spores of *jowar Helminthosporium* are straight, spindle-shaped and resemble those on maize from Burma, Almora and Dharwar, but spores from Pusa specimens are a little curved and narrower and so differ somewhat from *jowar Helminthosporium* and maize *Helminthosporium* from Burma, Almora and Dharwar. The external characters, *i.e.*, spot formation and colour, etc., in Burma, Almora, Dharwar, Pusa and Malda specimens are the same, but in culture Pusa maize *Helminthosporium* has spores which are not so curved.

Conidiophores on *jowar* are more straight and bent at the tip but in the case of maize some are straight while others bent in a zig-zag manner. Maize conidiophores are slender and longer while those on *jowar* are thicker.

CULTURES.

A careful search was made in Pusa and in the neighbouring places in 1918-20 but no *Helminthosporium* was found on this host. Later on it was obtained from the leaves of *jowar* from the Punjab (Amritsar and Lyallpur) where this fungus is generally found after the rains. The culture was taken as in the case of maize fungus.

Spore germination is like that of maize *Helminthosporium* and needs no description.

Growth in different cultural media. The fungus was cultivated on a large number of culture media, and in many cases this fungus and maize *Helminthosporium* were grown together on the same kind of media for comparison. The fungus can grow well on most of the media tried and produces a large number of spores.

The fungus resembles maize *Helminthosporium* in most respects. The formation of conidia on conidiophores and the other details are somewhat like those of maize *Helminthosporium*. Though this fungus resembles the one on maize in the formation of spores, etc., and produces the same colour on the medium, there is a constant difference, *viz.*, that *jowar Helminthosporium* never produces a copious aerial growth on any of the media tried, and there is always a tendency to produce more of submerged and creeping mycelium, while in the case of maize there is a good aerial growth. On the other hand, this fungus always produces a very large number of conidia and sometimes the spore formation is so abundant that the contents of the mycelium are almost used up. The following media were tried :—

1. *Nutrient glucose agar.* Growth almost submerged and of dark greyish green colour with very little aerial growth. The growth is little more at 30°C. than at 20-22°C. with a good deal of spore formation. Conidia on this medium are 70 to 122·5 by 17·5 to 22·7μ while those of maize *Helminthosporium* on the same medium are 63 to 126 by 15·8 to 22·7μ in diameter.

2. *French bean agar.* The growth on this medium resembles very much that of maize *Helminthosporium* but *jowar Helminthosporium* is darker. The growth at 30°C. is more than that at 20-22°C. There is a good deal of spore formation.

3. *Wheat-meal agar.* The growth is like that of maize fungus but darker. Later on submerged and creeping dark greyish green mycelium is formed at 30–32°C. In the case of

maize *Helminthosporium* the colour is light greyish green but here it is dark greyish green and moreover aerial growth is absent. After some time little aerial growth appears but still the growth is darker than that of maize. Spore and mycelium resemble somewhat maize *Helminthosporium.* About 50 per cent. of *jowar* spores resembles the maize fungus but the remaining spore percentage is somewhat broader. The number of septa is the same in both.

4. *Jowar-meal agar.* There is a creeping and submerged growth of light greenish colour at 30°C., and crowded and compact at 22°C. The colour of medium becomes similar to maize fungus but afterwards it becomes dark green. After 10 or 12 days little aerial growth of dark greyish green colour appears. Spore formation is good.

5. *Litmus lactose agar.* The growth is poor and dark and greyish green, submerged and creeping in the beginning. The submerged portion becomes dark. Later on a little aerial growth appears. The growth on this medium is exactly like that of maize *Helminthosporium* on it. Spores are 45·6 to 95 by 15·2 to 22·8μ in diameter. The spores and mycelium resemble maize *Helminthosporium* on this medium, the size, form and colour being alike.

6. *Coon's synthetic agar.* Fairly good at 30–32°C. of dark green colour. The growth resembles to some extent maize *Helminthosporium* on this medium. The fungus is more dark green at 22°C. Spore formation poor and the old mycelium becomes gemmate. The mycelium is darker than that of maize *Helminthosporium.*

7. *Corn-meal agar.* Growth dark greyish green at 22°C., and light at 32°C. Submerged growth is greenish and there is no aerial growth Later on little aerial growth appears which is very much like that of maize and of greenish grey colour. The mycelium and spores resemble those of maize *Helminthosporium.* After 10 or 12 days maize and *jowar* cultures resemble very much on this medium. Spores and mycelium almost alike and spore formation more at a low temperature of 20 to 22°C. than at 30–32°C. Spores are 80·5 to 122·5 by 15·8 to 21μ in diameter while those of maize *Helminthosporium* are 77 to 122 by 15·8 to 19μ.

8. *Oat-meal agar.* Dark creeping growth at both temperatures but little more at 32°C. After some days growth appears dark greyish green, creeping and submerged. Spore formation is good. The mycelium resembles that of maize *Helminthosporium.* On this medium the aerial growth is comparatively smaller.

9. *Nutrient saccharose agar.* Creeping and submerged growth of dark grey colour with little aerial growth and poor spore formation.

10. *Thaxter's hard potato agar.* Dark green, submerged and creeping, resembling the growth of maize *Helminthosporium* but there is no aerial growth. After some time little aerial growth appears. Spore formation resembles that of *Helminthosporium* on maize.

11. *Wheat straw.* Wheat straw was sterilized in ordinary tubes containing little water. The fungus was grown on it and the tubes were kept at 27–30°C., and some at 22°C. There was a good production of spores on it. The growth was like that of maize, but in the latter case more spores were formed. In these, there was no good aerial growth. Greyish green mycelium was formed at the bottom of the tube in water.

From the results of inoculation experiments and from cultural characters this fungus appears to be very closely related to or identical with *Helminthosporium* on maize, but the fact that in one place it occurs on one host and not on the other, makes one to consider them as two different varieties of *H. turcicum* Pass.

Cross-inoculation experiments.

The following cross-inoculations were made with *jowar Helminthosporium* on the same hosts on which maize *Helminthosporium* was inoculated and in the same manner.

TABLE X.

Cross-inoculations on maize.

No.	Date	No. of inoculations	No. infected	Control	Control infected	REMARKS
1	29-11-19	8	5	1	..	
2	30-1-20	10	6	1	..	
3	21-5-20	10	4	1	..	
4	10-6-20	14	10	1	..	
5	7-8-20	10	5	1	..	
6	11-12-20	10	..	1	..	
	Total	62	30	..	..	48%

Forty-eight per cent. of inoculated maize were infected and produced spots which resembled very much the spots formed by the maize *Helminthosporium* on maize. It appears that maize *Helminthosporium* and *jowar Helminthosporium* are the same, but with slight differences in cultural characters and in the form of spores.

TABLE XI.

Cross-inoculations on sugarcane.

No.	Date	No. of inoculations	No. infected	Control	Control infected	REMARKS
1	29-11-19	10	8	1	..	No infection took place probably on account of low temperatures prevailing at the time.
2	11-12-20	10	0	1	..	
	Total	20	8	..	..	40%

Forty per cent. of inoculated sugarcane leaves were infected. The spots formed were small, oval and, later on, dirty brown with brownish rings. They gradually increase in size, more in the longitudinal direction, and produce conidia and conidiophores which have normal character.

TABLE XII.

Cross-inoculations on bajra.

No.	Date	No. of inoculations	No. of successful inoculations	Control	Control infected	REMARKS
1	29–11–19	20	0	1	..	0%

No infection took place. It may be mentioned here that maize *Helminthosporium* also had no effect on *bajra*.

TABLE XIII.

Cross-inoculations on paddy.

No.	Date	No. of inoculations	No. of successful inoculations	Control	Control infected	REMARKS
1	29–11–19	10	2	1	..	
2	20–6–20	10	2	1	..	
3	7–8–20	10	0	1	..	
	Total	30	4	..	..	13%

Out of 30 inoculations made, 4 were infected and these also showed simply penetration and very little spreading in the tissue of rice leaves. The growth ceases soon and there is no spore formation. Maize *Helminthosporium* also behaves like this on paddy.

TABLE XIV.

Cross-inoculations on wheat.

No.	Date	No. of inoculations	No. of successful inoculations	Control	Control infected	REMARKS
1	25–1–20	14	5	1	..	
2	6–2–20	10	10	1	..	
3	7–4–20	15	6	1	..	
4	3–2–21	17	17	1	..	
	Total	56	38	..	..	69%

Sixty-nine per cent. of wheat plants were infected when inoculated. The fungus penetrated and at the point of infection the leaves withered and broke. There was spore formation on both sides of leaves.

TABLE XV.

Cross-inoculations on barley.

No.	Date	No. of inoculations	No. of successful inoculations	Control	Control infected	REMARKS
1	7–4–20	15	5	1	..	
2	3–2–21	12	5	1	..	
	Total	27	10	..	..	37%

Jowar Helminthosporium can infect barley leaves but the infection is not vigorous. The spots formed stop growing after sometime and spore formation is not plentiful.

TABLE XVI.

Cross-inoculations on oats.

No.	Date	No. of inoculations	No. of successful inoculations	Control	Control infected	REMARKS
1	6–2–20	12	8	1	..	
2	7–4–20	10	3	1	..	
3	3–2–21	12	3	1	..	
	Total	34	14	..	..	41%

As in the case of barley, on oats also infection is not vigorous and the fungus stops growing in the tissue after some time.

These experiments show that *jowar Helminthosporium* can infect –

Jowar	79%	Maize	48%	Sugarcane	40%
Wheat	69%	Oats	41%	Barley	37%
Rice	13%	*Bajra*	0%		

From the above figures it will appear that about 50 per cent or more infection takes place on wheat and maize, and in the case of sugarcane, oats and barley about 40 per cent. *Jowar Helminthosporium* has very little effect on rice, and *bajra* is immune to its attack.

4. Summary.

1. *Helminthosporium* is found on almost all cereals and sugarcane in India. The present paper deals with species on *Zea Mays* (maize) and *Sorghum vulgare*)*jowar*).

2. *H. turcicum* Pass. on maize and *jowar* is morphologically identical. Both strains show some difference in culture, and it has been observed that in Bihar *Helminthosporium* is found only on maize and not on *jowar*, while in the Punjab it is recorded only on *jowar*. It is these two facts that lead the writer to believe that the fungus on *jowar* is a different strain from that on maize.

3. *H. turcicum* Pass. on maize is found in almost all countries where maize is grown and in Bihar it is one of the important diseases of this crop. The fungus is found both on leaves and on male inflorescence and its parasitic nature is proved by inoculation experiments on both hosts.

4. *H. turcicum* Pass. can be grown on a large number of media but the perfect stage of this fungus has not been observed on any of the media. The fungus prefers a reaction of 0 to +5 Fuller's scale.

5. The infection takes place either through a stoma or by piercing the cuticle and entering the cell below.

6. Cross-inoculation experiments show that both the strains of *Helminthosporium* on maize and on *jowar* can infect maize, *jouar*, wheat, barley, oats and sugarcane. The inoculations on *bajra* give negative results and those on rice were doubtful.

LIST OF ILLUSTRATIONS.

Plate I.

Fig. 1. An infected portion of a maize leaf showing spots formed by *Helminthosporium turcicum* Pass. (natural size).

,, 2. A portion of male inflorescence of maize infected with *Helminthosporium* (natural size).

,, 3. A leaf of *jowar* showing spots due to *Helminthosporium* (natural size).

Plate II.

Fig. 1. *H. turcicum* Pass. on maize. Germination of a spore drawn after 48 hours. × 136.

Figs. 2 & 3. *H. turcicum* Pass. on maize. Germination of a spore drawn after 18 hours. × 440.

Fig. 4. *H. turcicum* Pass. on maize. Germination of a spore drawn after 18 hours. × 640.

,, 5. *H. turcicum* Pass. on maize. Germination of a spore drawn after 18 hours. A continuous tube is formed by the disappearance of septa and germ tube is coming out. × 640.

,, 6. *H. turcicum* Pass. on maize. All the septa have been disorganized before the protrusion of germ tube. × 460.

Figs. 7–13. *H. turcicum* Pass. Spores from Pusa maize leaf. × 460.

,, 14–17. *H. turcicum* Pass. Spores from Burma maize leaves. × 460.

,, 18 & 19. Conidiophores seen in a transverse section of an infected maize leaf. In Fig. 18, all the conidiophores are coming out by piercing an epidermal cell near a guard cell. In Fig. 19, a conidiophore coming out by piercing the epidermis and cuticle is shown. × 640.

Fig. 20. Conidiophore. Section from a natural infected maize leaf. Conidiophore coming out by piercing the epidermis and cuticle. × 640.

,, 21. A section showing conidiophores coming directly from an epidermal cell of a maize leaf. × 640.

Figs. 22–25. Spores of *H. turcicum* Pass. from a diseased maize leaf from Almora × 700.

Plate III.

Fig. 1. Maize *Helminthosporium.* Penetration of hypha through cell next to a guard cell of a stoma in maize. × 700.

,, 2. Maize *Helminthosporium.* Penetration through a stoma of maize. × 700.

,, 3. Maize *Helminthosporium.* Penetration and spread of fungus in the tissue of maize leaf. Section was cut after 36 hours of inoculation. × 640.

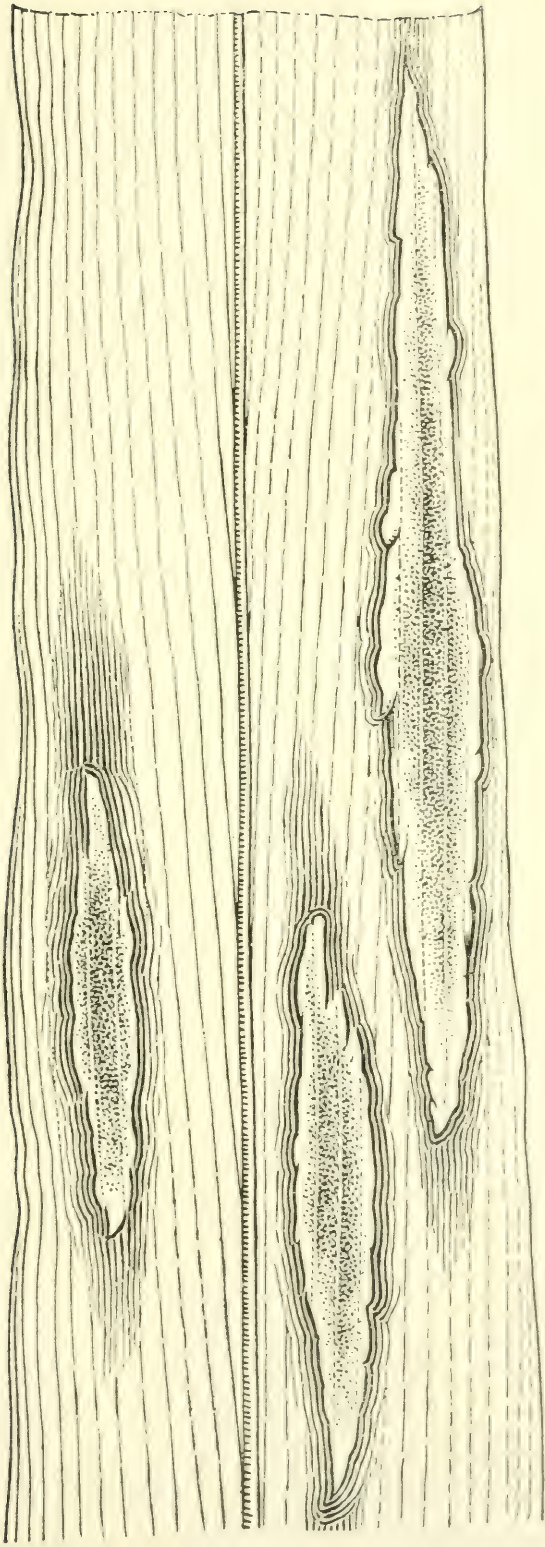
Figs. 4 & 5. Maize *Helminthosporium.* Hyphæ penetrating into the tissue of sugarcane leaf. × 640.

Fig. 6. *Jowar Helminthosporium.* Penetration of a hypha into the leaf of *jowar* through a stoma. × 700.

Figs. 7–11. Spores of *jowar Helminthosporium.* × 640.

,, 12–16. Conidiophores of *jowar Helminthosporium.* × 640. (Fig. 16. Tip of a conidiophore.)

PLATE I.



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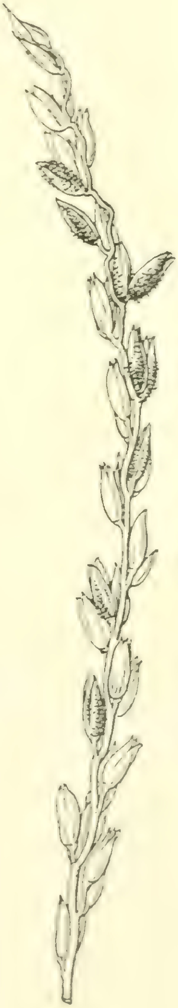

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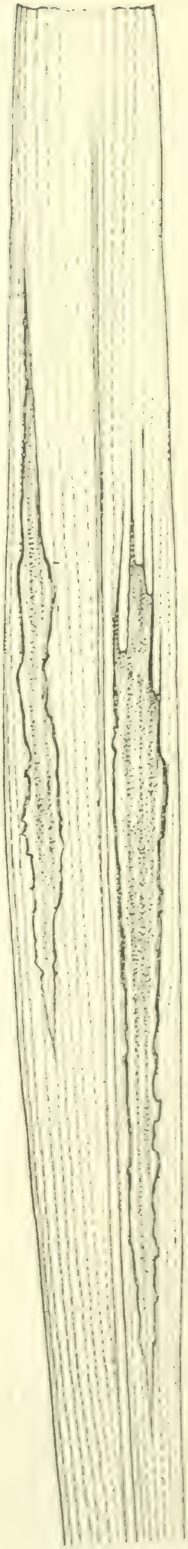

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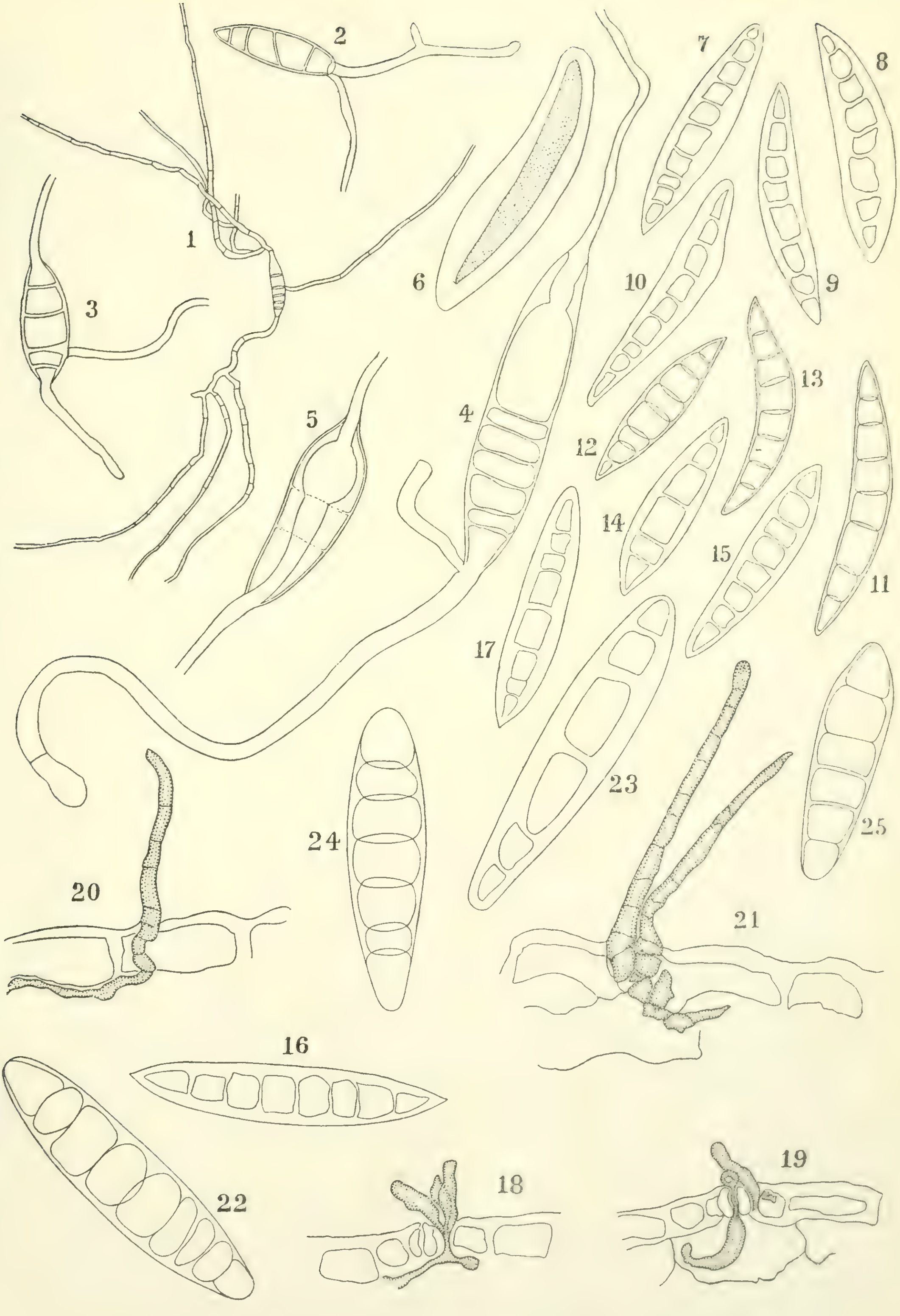
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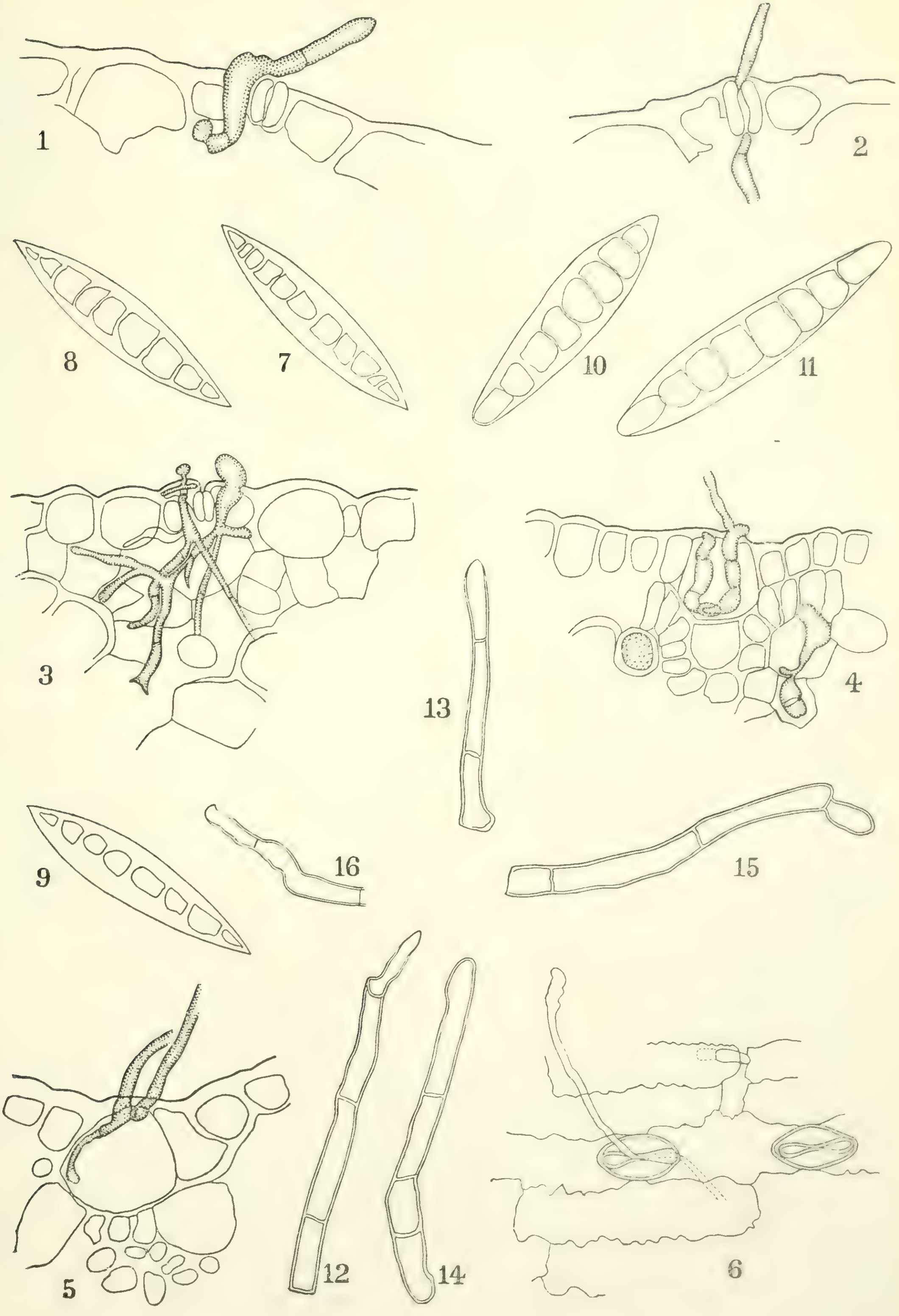
HELMINTHOSPORIUM ON MAIZE AND *SORGHUM*.

PLATE III.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